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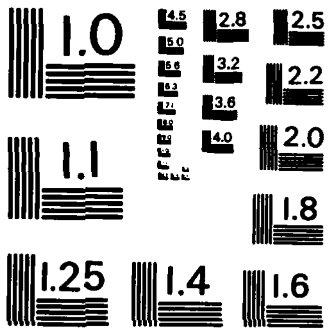

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This report is a case-history evaluation of the effects of fluctuating reservoir water levels on the density and biomass of individual fish species or groups of fish species in hydropower storage, hydropower mainstream, and flood control reservoirs using correlation analysis and stepwise multiple regression. Correlation analysis was used to rank seasonal hydrologic variables according to their importance in predicting the abundance of reservoir fish. Stepwise multiple regression was used to generate regression equations describing the
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relationship between easily obtained hydrologic data and fish for 11 study reservoirs. In many cases, these equations can be used either to predict the effects of altering seasonal water levels in existing Corps of Engineers reservoirs or to predict which of several reservoir operation alternatives for a new reservoir will have the least negative effect on the reservoir fishery.

PREFACE

This report was prepared by the U. S. Department of the Interior, U. S. Fish and Wildlife Service, National Reservoir Research Program (NRRP), with the assistance of the Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), under Intra-Army Order WESRF 83-64, dated 15 November 1982. The study comprises part of the Environmental and Water Quality Operational Studies (EWQOS), Task IIE, "Environmental Effects of Fluctuating Reservoir Water Levels." The EWQOS Program is sponsored by the Office, Chief of Engineers, U. S. Army (OCE), and is assigned to the WES under the management of EL. The OCE Technical Monitors for EWQOS were Mr. Earl E. Eiker, Dr. John Bushman, and Mr. James L. Gottesman.

This report was prepared for use by Corps of Engineer biologists or fishery biologists in predicting the effects of altering seasonal water levels in existing reservoirs or in predicting which of several reservoir operation alternatives for a new reservoir will have the least negative effect on the reservoir fishery. The document provides background information on the topic and outlines a predictive method based on multiple regression. Detailed guidance on the predictive method can be obtained from a companion Engineer Technical Letter entitled "Predicting Effects of Seasonally Fluctuating Water Levels on Fish Biomass and Density in Hydropower Storage, Hydropower Mainstream, and Flood Control Reservoirs."

This technical report was written by Mr. G. R. Ploskey and Dr. L. R. Aggus, Fishery Biologists (Research) of the NRRP, and Dr. J. M. Nestler of the EL. Mr. R. M. Jenkins was the Director of NRRP. The work was under the direct supervision of Dr. Nestler and the general supervision of Mr. D. L. Robey, Chief, Ecosystem Research and Simulation Division. Dr. J. L. Mahloch was the Program Manager, EWQOS, and Dr. John Harrison was Chief, EL.

The Commanders and Directors of WES during the study and preparation of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. The Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

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CONTENTS

EFFECTS OF WATER LEVELS AND HYDROLOGY ON FISHERIES IN HYDROPOWER STORAGE, HYDROPOWER MAINSTREAM, AND FLOOD CONTROL RESERVOIRS

PART I: INTRODUCTION

1. The storage and release of impounded water may result in significant water-level fluctuations within Corps of Engineers (CE) reservoirs. Fluctuating water levels within the reservoir may have considerable impact on the reservoir fishery; however, these impacts have, historically, been difficult to quantify. The state of the art of knowledge of the effects of fluctuating water levels on reservoir biota probably was summed up by a panel of experts who attended a workshop on the research needs for including ecological issues in basin-level hydropower planning (Hildebrand and Goss 1981). The panel concluded that although the capability to predict water-level changes was adequate, the ability to predict the biological consequences was not. They also concluded that predictability of effects of water-level changes on plants and aquatic invertebrates was poor and that effects on fish had not been quantified except to determine optimum or minimum requirements for spawning. The consensus of the panel was that the ability to address ecosystem-level effects was qualitative at best.

2. Most of the papers that compose the extensive volume of literature about the effects of reservoir water levels on aquatic biota are qualitative descriptions of the positive or negative effects on species of plants, invertebrates, or fish and were designed primarily as pre- and post-treatment evaluations of a single fluctuation or manipulation event. When applied at all, statistical analyses usually were limited (by necessity) to paired tests (*t* tests) of significance. Some studies that went beyond simple pre- and post-treatment evaluations were done by Johnson (1957), Wood and Pfitzer (1960), Jenkins (1967, 1970), Derkson (1967), Nelson (1968), Jenkins and Morais (1971), Aggus and Elliott (1975), Chevalier (1977), and Nelson and Walburg (1977) and

consisted of multiple regression analyses with small sample sizes. Bibliographies by Triplett et al. (1980) or Ploskey (1982), and papers by Wood and Pfitzer (1960), Keith (1975), Groen and Schroeder (1978), and Ploskey (1983) provide detailed reviews of the literature on the effects of water-level fluctuations on reservoir biota.

3. The major objectives of this report are to quantify the effects of fluctuations in reservoir water levels and hydrology on resident fishes and to develop a predictive methodology for evaluating the ecological consequences of existing or proposed water-level regimes in CE impoundments. The objectives are achieved by employing multiple regression (using fish biomass and density as dependent variables and seasonal hydrologic indices as independent variables) to:

- a. Determine which seasonal hydrologic events have the most impact on fishes.
- b. Determine whether existing plans for enhancing fisheries by managing water levels could be substantiated by quantitative data.
- c. Recommend water-level regimes to benefit important groups or species of fish.
- d. Provide regression models for predicting the effects of existing or proposed regimes of hydrology on fishes in three types of impoundments (hydropower storage, hydropower mainstream, and flood control).

Items a and d were emphasized to increase the value of this report for practical applications.

4. Inasmuch as regression models may be hypotheses about causes and effects, and underlying reasons for observed relations are not always obvious from the equations, discussion concerning the possible biological or limnological basis for each relation was limited. Findings from the hydropower storage data set are discussed the most thoroughly because it contained the most comprehensive data and was also composed of reservoirs with the most similar operational and physical characteristics. In addition, effects of changes in water levels on fish were more pronounced in storage than in mainstream reservoirs. The findings from the flood control projects were the most difficult to interpret since the results were not consistent.

Additionally, the operational and physical characteristics of the flood control projects varied widely.

PART II. DATA AND STATISTICAL METHODS

5. Data on August fish density and biomass and on monthly surface area and water exchange rates were collated into three data sets, according to reservoir type (hydropower storage, hydropower mainstream, or flood control). Fish data were collated from the files of the National Reservoir Research Program (NRRP) but were originally collected by the Tennessee Valley Authority (TVA), NRRP, and state fishery agencies. Hydrologic data were obtained from the U. S. Geological Survey's "Water Resources Data" for the different states in which reservoirs were located.

Reservoir Characteristics

6. Characteristics of the reservoirs for which both hydrologic and fishery data were obtained (Table 1) clearly show the morphological and operational features that distinguish the three types of impoundments. The hydropower storage reservoirs were large (extensive surface area), deep, and dendritic (high shoreline development index). Shoreline development (D) is a comparative figure that relates shoreline length to the circumference of a circle that has the same area as the reservoir. Storage reservoirs exhibit substantial annual fluctuations (2.4-4.9 m) and retain water longer than mainstream reservoirs (i.e., storage ratios are high). Annual storage ratios indicate the number of years required to replace the entire volume of a reservoir. Hydropower mainstream reservoirs are best characterized by rapid water exchange (low storage ratios) and small annual fluctuations in water levels. Flood control reservoirs usually have the most extensive changes in water levels and the lowest shoreline development. The average annual vertical fluctuations in the hydropower mainstream reservoirs were significantly less than those in the hydropower storage or flood control reservoirs. The average vertical fluctuation in the storage reservoirs did not differ significantly from that in the flood control impoundments. However, fluctuations in the flood control reservoirs consistently

covered more of the reservoir basin than fluctuations in hydropower mainstream or storage reservoirs (see Figure 1). The average annual change in surface area was only 14 and 23 percent of the average surface area in mainstream and storage reservoirs, respectively, but 88 percent in flood control reservoirs. Surface area was reduced in fall by an average of 55 percent in the flood control impoundments but only by 1.8 and 7.4 percent in mainstream and storage impoundments, respectively.

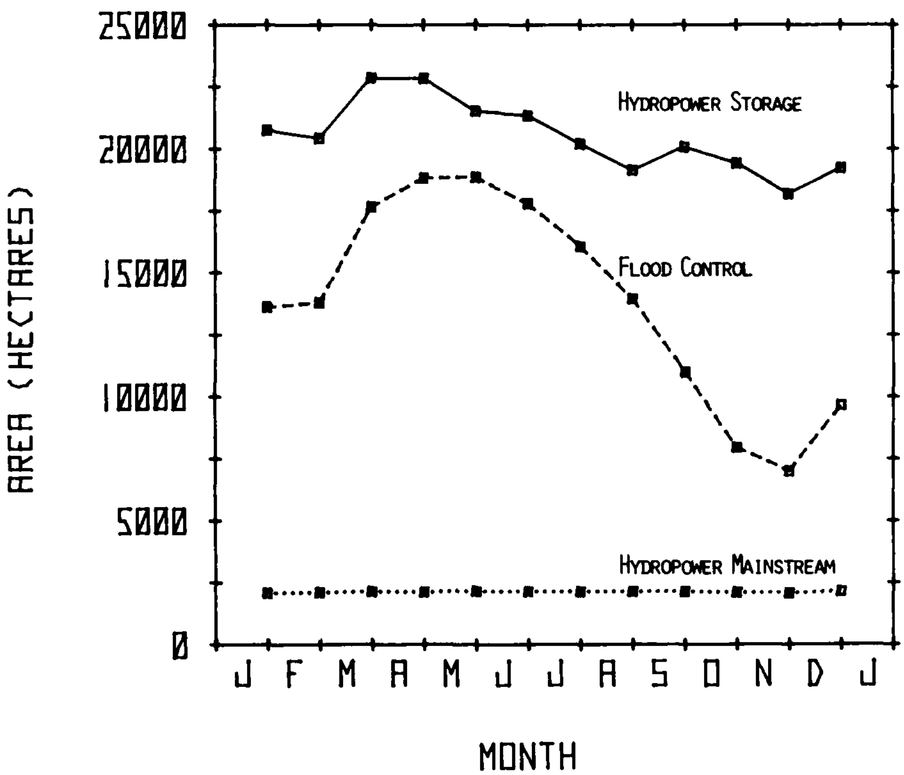

Figure 1. Seasonal changes in surface area in three types of reservoirs--hydropower storage (Kerr Lake, Virginia), flood control (Sardis Lake, Mississippi), and hydropower mainstream (Melton Hill, Tennessee)

Fishery data

7. The two dependent variables for regression analysis were fish biomass (kg/ha) and density (numbers/ha). Fish were collected in August by rotenone treatment of coves that were isolated from the reservoir with a large block net. Fish from the cove were collected, sorted to species, and measured to the nearest 25.4-mm size class. The number and weight of fish within size classes were then determined for every species or species assemblage of fish. A detailed explanation of typical cove sampling methodology was presented by Grinstead et al. (1977). Fish size-class biomass and density data were summed into three major size groups (small, intermediate, and large). For example, the biomass of largemouth bass in the first four 25.4-mm size classes (fish ≤114 mm) was summed to form the variable "small largemouth bass biomass." The biomass of largemouth bass in the next four size classes (fish >114 mm and ≤318 mm) was summed to create the variable "intermediate largemouth bass biomass." Largemouth bass >318 mm were considered to be "large," and their biomass and densities were summed accordingly. Maximum lengths of small and intermediate-size fish are listed in Appendix D along with common and scientific names. Large-size fish groups were not used for regression analyses because of the difficulty in establishing cause and effect relations between hydrologic variables and the abundance of large fish.

8. Dependent variables were standardized by reservoir to a mean of zero and standard deviation (SD) of one to eliminate inherent differences in the biomass and density of fish among reservoirs due to differences in fertility. Thus, by standardizing the data for each reservoir to a common mean and variance, fish data from separate reservoirs within each reservoir category could be pooled and analyzed by regression analysis.

Hydrologic data

9. Independent variables were derived from data on surface area at the end of every month and monthly storage ratios (average monthly volume/total monthly discharge) for the reservoirs and years in which fish data were available. Independent variables, their abbreviations,

definitions, and means ± SD for the three data sets are presented in Table 2. Monthly storage ratios express the number of months required to replace all of the water in a reservoir. Consequently, low monthly storage ratios indicate rapid rates of water exchange. Independent variables were standardized by reservoir to a mean of zero and SD of one. Data were standardized to minimize the spurious effects of differential size and flow in different reservoirs. Standardized deviates were paired, according to reservoir and year, with deviates for fish biomass and density. Standardization does not eliminate the differential effects of various operational regimes on fish (e.g., the timing and extent of drawdowns in reservoirs of the same type). When data from several reservoirs with different operational regimes are standardized and pooled for regression, an unknown amount of unexplained variation is unavoidably introduced. This problem was most pronounced in flood control reservoirs.

Data Limitations

10. Cause-effect relations between water-level variables and fish biomass or density in size groups can be difficult to establish without information on the age of fish when they recruit to the next larger size group. Both growth and annual survival vary among reservoirs, and even among years within the same reservoir. Cause-effect relations undoubtedly exist between hydrologic variables and the abundance of young-of-year (YOY) fish in August because of effects on reproduction and survival. Also, yearling fish could be directly affected by water-level variables if their growth and survival were altered in their first year of life. But, water-level changes during the year preceding collection probably will not change the abundance of large fish unless the fish move out of the reservoir or die. For example, the number of large carp in a reservoir may be determined by a hydrologic event that occurred 3 years earlier. Consequently, the "large-size groups" (adults) of fish were not ordinarily used for regression analyses.

11. Inspection of plots of standard normal deviates of biomass or

density in consecutive years for small, intermediate-size, and large-size groups of fish can help illustrate fish recruitment and identify some of the major problems associated with assigning cause and effect between reservoir hydrologic conditions and fish crop. Such plots also show that water-level management can eventually (in 1-6 years, depending on the species and growth) increase the abundance of large, harvestable-size fish by creating strong year classes. Figures 2 through 6 present changes in the biomass of small, intermediate, and large fish over time in Clark Hill Lake and Bull Shoals Lake (hydropower storage reservoirs). These particular figures are presented because they best illustrate the recruitment of YOY fish into the larger size classes.

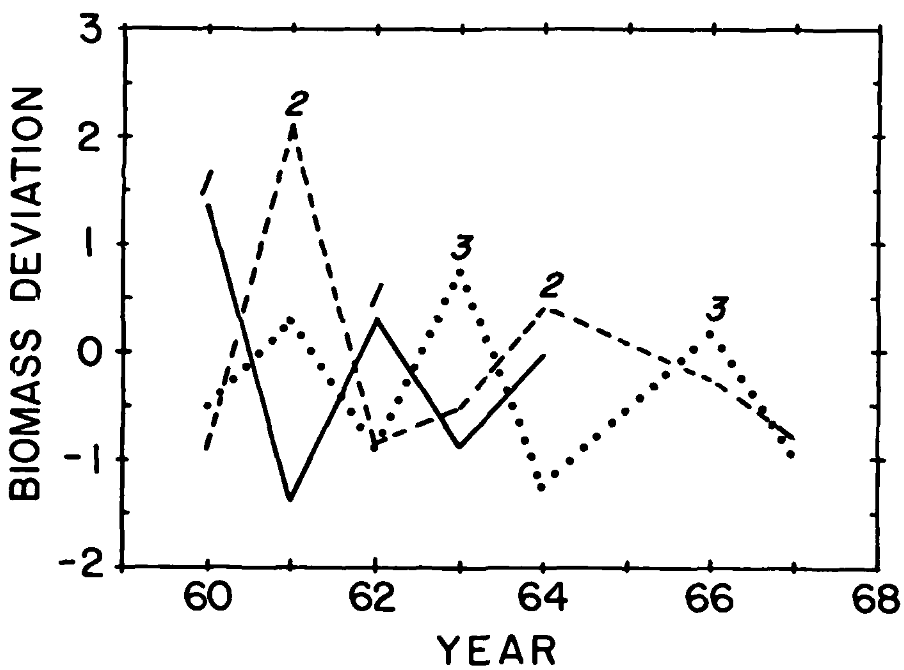

Figure 2. Standard normal deviations in the biomass of small (≤114 mm; solid line), intermediate (114 < mm total length (TL) ≤ 318; dashed line), and large (>318 mm; dotted line) largemouth bass in Clark Hill Lake, Georgia, from 1960 to 1967. The numbers 1, 2, and 3 indicate years of above-average biomass of small, intermediate, and large fish, respectively.

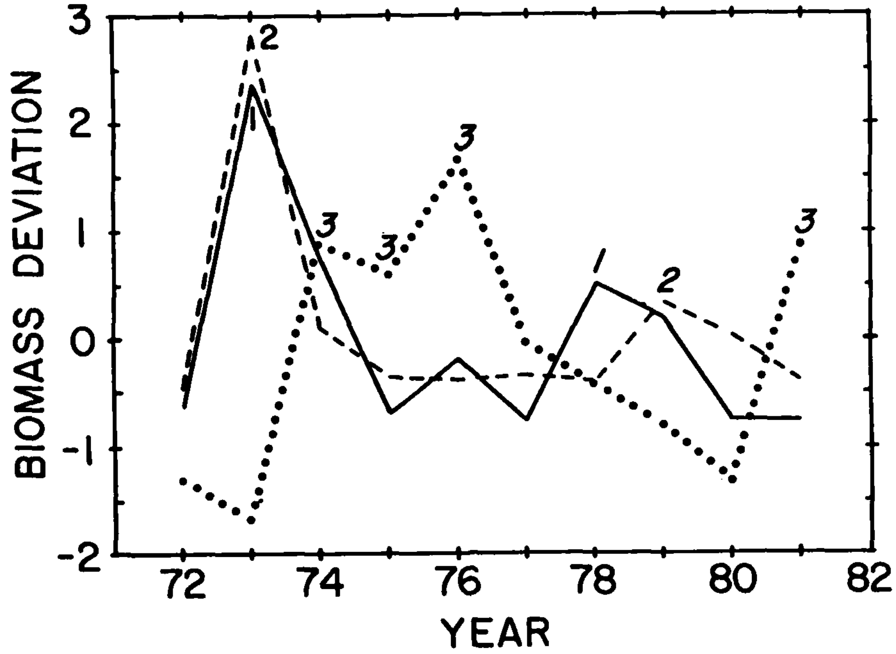

Figure 3. Standard normal deviations in the biomass of small ($\leq$114 mm; solid line), intermediate (114 < mm TL $\leq$ 318; dashed line), and large (>318 mm; dotted line) largemouth bass in Bull Shoals Lake, Arkansas, from 1972 to 1981. The numbers 1, 2, and 3 indicate years of above-average biomass of small, intermediate, and large fish, respectively.

12. Figure 2 shows changes in the biomass of largemouth bass in Clark Hill Lake, Georgia, from 1960 to 1967. The line at zero on the ordinate axis indicates the average biomass in the reservoir. Plotted values reflect annual increases or decreases in the mean biomass of fish measured in standard normal deviation units. The numbers 1, 2, and 3 in the figure denote years of above-average biomass for small, intermediate, and large fish, respectively. Inspection of Figure 2 illustrates two important points.

a. Growth varies greatly from year to year in the same reservoir. For example, most of the small largemouth bass produced in 1960 grew into the intermediate size group in one year, appearing as a peak in the biomass of intermediate-size fish in 1961, whereas those produced in 1962 required about 2 years to recruit to the next larger size group.

b. Above-average biomass of small fish usually will produce an above-average biomass of large fish, but the number of years required for recruitment to the largest size is variable. For example, a majority of small fish produced in 1960 (Figure 2) required 3 years to exceed 318 mm TL, whereas most of those produced in 1962 needed 4 years.

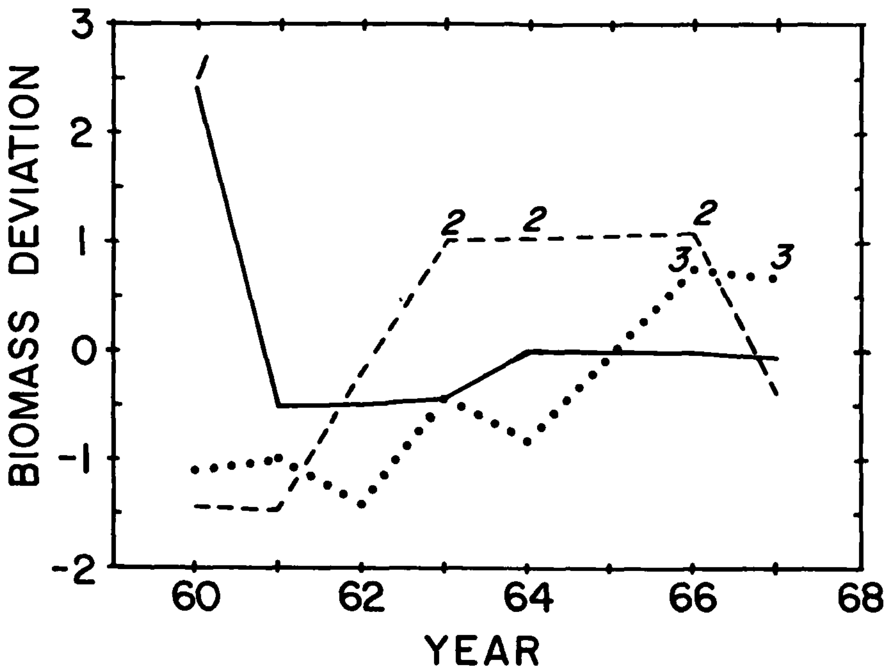

Figure 4. Standard normal deviations in the biomass of small ($\leq$114 mm; solid line), intermediate (114 < mm TL $\leq$ 241; dashed line), and large (>241 mm; dotted line) gizzard shad in Clark Hill Lake, Georgia, from 1960 to 1967. The numbers 1, 2, and 3 indicate years of above-average biomass for small, intermediate, and large fish, respectively.

13. Points a and b above are also illustrated in Figure 3, which shows 10 consecutive years of data from Bull Shoals Lake, Arkansas. In 1973, a year of extremely high water levels, the biomass of small and intermediate-size largemouth bass was above average. The YOY fish grew rapidly (exceeding 114 mm TL by August, with some exceeding 254 mm) and recruited to the intermediate-size class in the same year. This observation was verified by growth data from scale samples (NRRP, unpublished data). A year later (1974), young fish recruited to the largest size group by exceeding 318 mm TL. Comparison of the above recruitment

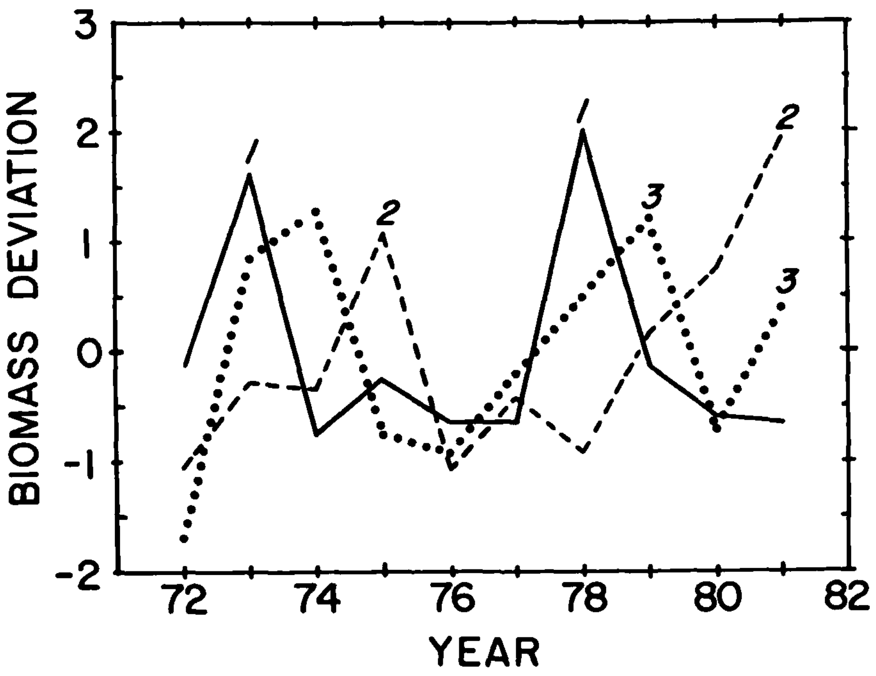

Figure 5. Standard normal deviations in the biomass of small ($\leq$114 mm; solid line), intermediate (114 < mm TL $\leq$ 318; dashed line), and large (>318 mm; dotted line) flathead catfish in Bull Shoals Lake, Arkansas. The numbers 1, 2, and 3 indicate years of above-average biomass of small, intermediate, and large fish, respectively.

pattern to that of largemouth bass in Clark Hill Lake (Figure 2) demonstrates that growth varies among as well as within reservoirs. The strong year class produced in 1973 in Bull Shoals Lake (Figure 3) resulted in above-average crops of large fish lasting 3 years (1974-1976), substantially longer than most peaks of large fish observed in this study. Mean spring and summer surface areas in 1973 were 4,383 and 5,617 ha greater, respectively, than they had been in 1972; in 1974 they were still 1,541 and 3,456 ha greater than in 1972. Average summer areas exceeded average spring areas by 1,513 and 2,194 ha in 1973 and 1974, respectively. The biomass of small largemouth bass was also above average in 1978 and 1979, years when spring and summer water levels were again above average. The high biomass of small largemouth bass in 1978 and 1979 resulted in an above-average biomass of large largemouth bass in 1981, 3 years later.

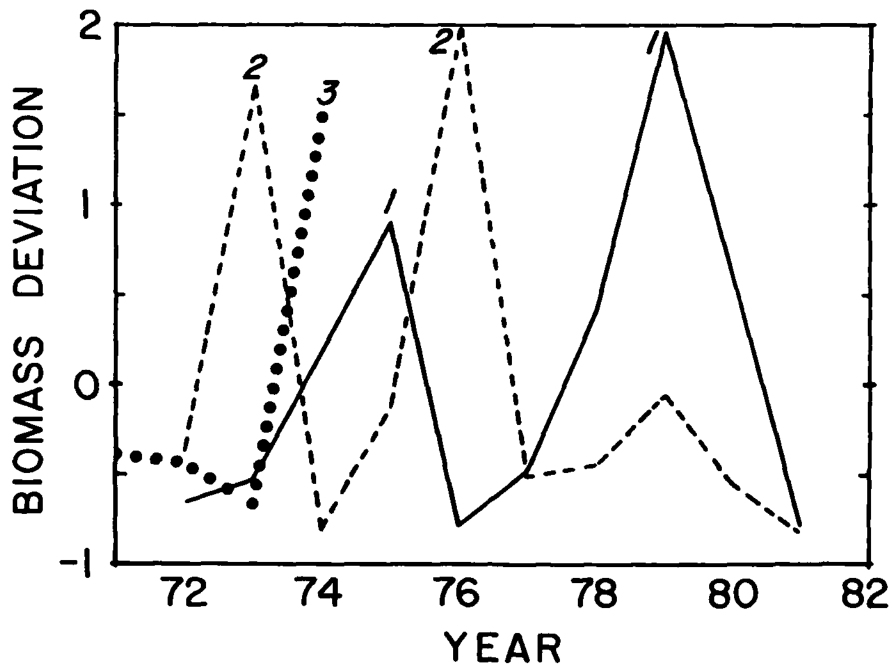

Figure 6. Standard normal deviations in the harvest (dotted line) and the biomass of small (≤114 mm; solid line) and intermediate-size (114 < mm TL ≤ 318; dashed line) white bass in Bull Shoals Lake, Arkansas, from 1972 to 1981. The numbers 1 and 2 indicate years of above-average biomass for small and intermediate-size fish, respectively; the number 3 denotes a year of above-average harvest.

14. Species such as gizzard shad and flathead catfish, which recruit infrequently and often stack up at intermediate sizes because of slow, density-dependent growth, have an overall recruitment pattern similar to that of largemouth bass, except that it is drawn out over more years (compare Figure 4 with Figures 2 and 3). Six years were needed for small gizzard shad to grow and recruit to the largest size group (>241 mm TL) after they first appeared as small fish in 1960. Flathead catfish in Bull Shoals Lake (Figure 5) also required 6 years to recruit to their largest size group (>318 mm TL) after they were produced in 1973, but most of those produced in 1978 needed only 3 years to become large fish.

15. Caution must be exercised when concluding that a species was not affected by hydrologic variables. Many species (e.g., white bass

and white crappie) are not sampled adequately in cove samples because they are more pelagic than other species. Additionally, assigned limits for small size groups (Appendix D) may not delimit YOY fish every year. One might conclude incorrectly from Figure 6 that the production of YOY white bass was unaffected or negatively affected by high water in 1973 because the biomass of small white bass was below average that year. Actually, extremely high water levels in 1973 resulted in an above-average biomass of intermediate-size white bass by August because YOY grew beyond the upper limit of the small size group (114 mm), and most managed to attain 254 mm by August. The biomass of YOY white bass would have been above average in 1973 only if the YOY fish had exhibited average growth. The biomass of large white bass is not represented in Figure 6. The reason is not that highly successful reproduction in 1973, 1975, and 1979 had no effect on the biomass of large white bass, but that large white bass were never sampled adequately in cove samples. Standardized creel data on the harvest (kilograms/hectare) of white bass in 1971-1974 (Figure 6) demonstrate that large white bass were probably more abundant in 1974 than in the previous 4 years. The harvest of white bass increased from 1.6 kg/ha in 1973 to 21.1 kg/ha in 1974, as white bass from the 1973 year class recruited to the fishery.

PART III. REGRESSION ANALYSES

Evaluation

16. Multiple regression analyses of fish variables against hydrologic variables were performed using the "maximum R^2 improvement" (MAXR) technique in the Statistical Analysis System Release 79.4 (Barr et al. 1979). The criteria used to select the most appropriate regression equation generated by this procedure were: (a) level of significance of model and parameter estimates, (b) the change in mean square error (MSE), (c) the coefficient of determination (R^2), and (d) the logic of positive or negative correlations. The first three selection criteria were described by Neter and Wasserman (1974). The fourth criterion compared effects generated by the analyses to those documented in the literature to avoid including potentially spurious models that were statistically significant but biologically unexplainable.

17. Two different strategies were used to describe the effects of fluctuating water levels on reservoir fish. A general description of the effects of fluctuating water levels on the entire reservoir fishery was obtained by examining the frequency with which the different hydrologic variables occur in the correlation matrix. Variables of particular importance can be identified in this way. The second approach describes the reaction of species or small groups of species of fish to specific hydrologic variables as indicated by individual regression equations.

18. In the first approach, each independent water-level variable was discussed in the order of its relative importance, and examples of fishes that were positive or negative correlates to each independent variable were listed. Water-level variables were ranked according to their relative importance by tallying the number of significant correlations at $\alpha = 0.05$, counting the number of fish groups affected, and evaluating the consistency of positive or negative relations for different taxa. The consistency of positive or negative correlations was determined by examining the number of positive and negative correlations significant at the $\alpha = 0.20$ level.

19. The second approach involved examining different species or groups of species and derived multiple regression equations that describe relations between fish biomass or density and the independent variable or variables. The "best" regression equations for each grouping and associated statistics are presented in Appendices A, B, and C. To avoid being redundant, the most significant equation with the highest coefficient of determination was selected whenever biomass and density variables were correlated with the same independent variable or variables.

Correlations Between Independent Variables

20. Correlations between independent variables can have undesirable effects on regression coefficients and on sums of squares that reflect the effects of single independent variables on a dependent variable in a multiple regression equation (Neter and Wasserman 1974). When independent variables are correlated, regression coefficients are not unique but depend on which other variables are in the model. They may not, by themselves, be significantly correlated with the dependent variable, and a reduction in the total variation cannot be ascribed to a single independent variable but must be viewed in the context of the other independent variables in the model. However, Neter and Wasserman (1974) point out that correlations between independent variables are usually not a problem when the purpose of regression analysis is to make inferences about response functions or to predict new observations, as long as inferences are made about responses in systems with a similar range of observations as the original data set.

21. The techniques and results developed by this study can be most effectively applied if the correlation pattern in the reservoir of interest is similar to that of the reservoirs presented in this report. In most instances, this should not be a problem since the correlations between independent variables for each reservoir type (flood control, hydropower storage, and hydropower mainstream) were generally similar, except for a few differences in summer and fall variables. Since differences in the correlation matrices of independent variables among the

reservoir types are relatively minor, it seems unlikely that a study reservoir would exhibit a pattern of correlations among the independent variables so different so as to preclude use of the results of this report, although this could happen if the underlying factors which determine the hydrologic characteristics of a study reservoir differ from those of the reservoirs described in this report.

22. The hydrologic patterns of reservoirs investigated in this report were primarily determined by year-to-year variations in inflow, which, in turn, were generally determined by precipitation. In years of above-average precipitation, most of the seasonal variables describing surface area and change in area were high, and variables reflecting hydraulic residence time in the spring were low. In drought years most of the variables related to changes in surface area and water levels were low or inconsistent, and variables indexing hydraulic residence time were high. Correlations between fall variables and the other variables were the least consistent among reservoir types, perhaps because fall variables are determined less by precipitation (which may dictate winter and spring water levels) than by flood control and peaking hydropower operation. The fall variables illustrate that the underlying factors characterizing the hydraulic conditions in some projects, particularly in flood control projects, may differ from those examined in this study and suggest that some degree of thought and caution should be exercised when examining each study reservoir.

23. Problems may arise when the predictive techniques described in this report are indiscriminately applied without regard to the factors described above. For example, maintenance of high spring water levels in a reservoir during a dry or average year may or may not have the anticipated effect on the reservoir fishery. The relationships between the variable "spring surface area" and the other hydrologic variables will differ from those observed in this study. Spring hydraulic residence time, for instance, will be substantially increased. In addition, the relationship between "spring surface area" and other, unmeasured variables will also be altered. In this study, higher than usual spring areas were caused by high spring inflows. The high spring inflows

also probably carried increased nutrient loads and may have had an effect on the reservoir thermal regime. Stratification may have been delayed or weakened by the large inflows. These effects would probably not be observed in a reservoir in which spring water levels were increased in a dry or average year. Consequently, the recommendations in this report designed to enhance reservoir fisheries can be most effectively used by taking advantage of suitable prevailing or anticipated hydrologic conditions. The recommendations should not be used as a "cookbook."

Hydropower storage reservoirs

24. Water level changes and hydrology in the hydropower storage data set illustrate the overriding influence of inflows. Water levels typically were lowest in fall, after drawdown. If fall area was above normal because of high runoff and if spring inflows were normal or above normal, then water levels were usually above normal in the following summer. The high water in the fall seemed to prevent above-average changes in area the following year, possibly because the reservoir could not be drawn down as effectively. Consequently, surface area in fall was positively correlated with area in the next summer (r = 0.38) but negatively with change in area the next year (Table 3). Winter-spring area was directly correlated with spring area (r = 0.92) and summer area (r = 0.43), and there was a positive correlation between spring and summer area (r = 0.54). The positive change in area from March to May was inversely related to the maximum change in area per year. In short, heavy spring inflows prevent excessive drawdown. In addition to its correlation with winter-spring and spring areas, summer area was inversely related to spring storage ratio (r = -0.40); that is, summer area was highest when water exchange rates were most rapid.

Hydropower mainstream reservoirs

25. The pattern exhibited by the correlation coefficients of the hydropower mainstream variables was generally similar to that observed in the hydropower storage data set, except that inflows had a greater effect on water level changes and operational control was minimal (Table 3). High inflows in mainstream reservoirs do not ensure high water in summer as they often do in storage impoundments because the

flows cannot be retained. The maximum change in area per year was not correlated with any other variables, indicating that no one event can determine the change in area over the course of a year, as in storage reservoirs. Area in mainstream reservoirs responds more immediately to changes in flow than area in other types of reservoirs and therefore fluctuates more often, though less extensively than in other types of reservoirs. Area in the fall was correlated with fall change in area (r = 0.59) only, and apparently was unrelated to water level changes in the following year, as it was in storage reservoirs. Storage ratio in the fall was not correlated to any other independent variables. Winter-spring area was directly correlated with spring area (r = 0.80) and summer area (r = 0.46) and inversely with spring storage ratio (r = -0.61); there were correlations between spring area and the variables summer area (r = 0.50) and spring storage ratio (r = -0.44). Change in area from March to May was inversely correlated with the change from June to August.

Flood control reservoirs

26. The pattern of the correlation coefficients in the flood control data also reflected the overriding influence of inflows on water levels and water exchange rates (Table 3). Area in the previous fall was positively correlated with area in the next summer (r = 0.35) but, unlike the hydropower storage reservoirs, was also positively correlated with the maximum change in area per year (r = 0.39). Apparently, if water levels are still high in late winter, additional rains in spring will cause above-average water levels in summer. However, by late summer or fall, drawdown finally will evacuate floodwaters, thus resulting in an above-average change in area for the year. As in the other types of reservoirs, winter-spring area was a positive correlate to spring area (r = 0.89) and summer area (r = 0.36), and low spring storage ratios (rapid water exchange) were associated with above-average area in winter-spring and spring as well as with change in area from March to May. Spring and summer areas also were correlated (r = 0.50). Drawdown of water levels from June to August, as indicated by summer change in area, was lowest after spring area was highest (r = -0.40),

probably indicating that drawdown is difficult to achieve when inflows are heavy.

Effects of Individual Hydrologic Variables on Fish

Hydropower storage reservoirs

27. Independent variables were ranked in order of importance according to the number of correlations significant at $\alpha = 0.05$. The variables, along with the numbers of significant ($\alpha = 0.05$) occurrences in the regression equations are: (a) spring area, 34; (b) annual change in area, 29; (c) summer area, 25; (d) spring change in area, 24; (e) summer change in area, 23; (f) winter-spring area, 19; (g) spring storage ratio, 13; (h) previous fall area, 13; (i) previous fall change in area, 4; (j) previous fall storage ratio, 2. Excluding annual change in area, the six most important variables deal with area or changes in area in spring and summer. These results are consistent with the literature, except that summer area was more important than most winter-spring or spring variables, with the exception of spring surface area. Previous research findings have emphasized the importance of spring water levels to fish reproduction and reproductive success (e.g., Benson 1976; Chevalier 1977). Results obtained in this study certainly support this emphasis, but they also indicate that water levels and changes in water levels in summer may be equally important in determining year-class strength because they strongly affect the survival and growth of young fish.

28. Further insight into the relationship between hydrology and the reservoir fish community can be obtained by listing variables that were either strongly positively or negatively related to the fish variables. Six of the hydrologic variables had positive effects on many fishes in the hydropower storage reservoirs. Listed in order of importance, with the percent of positive or negative correlation in parentheses, these variables were as follows: spring area (+93), annual change in area (+96), summer area (+89), spring change in area (+95), winter-spring area (+92), and fall change in area (+79). Summer change in area,

or drawdown (-89); spring storage ratio (-82); and area in the previous fall (-91) were inversely correlated with fish variables.

29. The effects of seasonal surface area on fish that were identified in this study corroborate previous findings of fishery research and management (Table 4). The first step in most water-level plans (e.g., Groen and Schroeder 1978) involves drawdown to a low pool level in fall. In this study, densities of intermediate-size black basses and largemouth bass in August were above average in years after a fall in which surface area was below average (Table 3). Reduced area in fall presumably concentrates prey for predators and enhances the survival of yearling piscivores (Benson 1973; Keith 1975). Reduced area in fall also permits seeding (Strange et al. 1982) or the natural development of terrestrial vegetation in the fluctuation zone. When flooded the next spring, herbaceous vegetation is believed to improve nesting and nursery sites of fish and thereby enhance spawning. Spring flooding after low water levels in fall inundates the fluctuation zone and supports above-average crops of fish. Nest-building fishes such as largemouth bass, spotted bass, and crappies clearly benefit from water levels that are low in fall and high in spring (Table 4). Density of intermediate-size smallmouth bass was the only variable that was negatively correlated ($\alpha = 0.01$; $r = -0.81$) with winter-spring and spring surface areas. A similar observation was made by Aggus (1979). The survival of smaller bass appears to be enhanced over that of other species of black basses because yearling smallmouth bass are better at using available rock substrates for cover to avoid predation (wave action will often create a rock-bottom area near the lower extent of the fluctuation zone). The biomass and density of small catfishes, small channel catfish, and flathead catfish were inversely correlated with surface area in the previous fall but were not positive correlates with spring area. Apparently, catfish reproduction is not enhanced by spring flooding, although the survival of yearling catfish is improved by increased food and cover made available by low fall area and spring flooding. Densities of gizzard shad in August were higher in years when the surface area was low the previous fall and high water levels occurred in spring. The

reproductive success of gizzard shad could benefit from vegetation grown in fall because it affords places for attachment of adhesive eggs and refuge for very young fish.

30. The many intermediate-size fish listed as positive correlates to winter-spring and spring area and the many small and intermediate-size fish listed as positive correlates to summer area strongly suggest that increased survival may be as important as enhanced reproduction in the formation of strong year classes. The positive responses of intermediate-size groups to high spring water levels might be accounted for in one of two ways: (a) fish in the intermediate-size group may have been YOY fish that grew out of the small-size group, or (b) survival of yearling fish in spring may have increased significantly. An examination of the numbers of YOY sunfish of several species in Bull Shoals Lake indicated that densities did not vary directly with spring water levels. Alternatively, the densities of yearlings could result from average numbers of YOY fish if water levels were high in spring of the second year and survival of YOY fish increased greatly. Only intermediate-size sunfish had positive correlations with spring and summer area (Table 4). An average number of 90-mm bluegills in the spring of their second year have an enormous survival advantage over the YOY bluegills because they can ingest larger prey and better utilize the abundant forage made available by spring flooding. In essence, they are like YOY fish that have hatched at 90 mm. If their mortality in spring and summer were reduced by 50 to 75 percent, they would significantly contribute to the abundance of intermediate-size bluegills.

31. All significant correlations between fall area and fish variables were negative, and all those between fish variables and area in winter-spring, spring, and summer were positive, except for those for intermediate-size smallmouth bass (Table 4). The consistency of results also is reflected in the positive correlations between area in spring or summer and the biomass or density of multispecies categories of fish such as all species, sport fishes, and minnows.

32. Correlations of fish variables with seasonal changes in surface area corroborate the correlations between seasonal surface area and

fish variables. Spring changes in area were positive in 95 percent of the years, and fall and summer changes in area were negative in 91 and 89 percent of the years, respectively. Table 5 lists the groups of fish that were positive correlates to the extent of drawdown in the fall of the previous year and with the amount of spring flooding. The fishes that were negative correlates to the magnitude of summer drawdowns also are listed. Thus, above-average biomass or density of many groups of fish result in part from water levels that are reduced more than average in fall, rise more than average in spring, and remain stable or are reduced less than usual in summer. Because walleye was the only species correlated at $\alpha = 0.05$ with the amount of fall drawdown, fish that were correlated at $\alpha = 0.20$ were also listed. The young of nest-building fishes such as the centrarchids in Table 5 were positively correlated with the extent of drawdown in the previous fall and with spring flooding. They were negatively correlated with the magnitude of summer drawdown. Results in the table also indicate that the reproduction of temperate basses and walleyes, which spawn in inflowing tributaries or headwater areas, may be improved by drawdowns in the fall of the previous year. Perhaps shoal areas are cleaned by water-level fluctuations, or low water levels in fall create more river-like conditions in the headwater regions after spring runoff arrives.

33. Improved production of many YOY fishes by above-average increases in spring surface area may be offset completely if the summer drawdown is excessive. Small black basses, largemouth bass, spotted bass, crappies, black crappie, and gizzard shad are listed as positive correlates to spring flooding and as negative correlates to the extent of summer drawdown. The abundance of intermediate-size spotted bass, green sunfish, white bass, threadfin shad, and sport fishes also was affected in the same way, presumably because survival and trophic conditions were improved by spring flooding and diminished by summer drawdown.

34. A simple method of comparing the relative effects of spring flooding and summer drawdown is to add the positive slopes of regression equations relating a fish variable to spring change in area to the

negative ones from equations relating the same fish variable to summer change in area. Differences should roughly indicate the net effect of both variables, assuming that the magnitude of spring and summer changes in area were equal. Thus, if the increase in spring area was substantially more important than extent of summer drawdown, the resultant sum of the slopes should have a large positive value. Conversely, if increase in spring area was not as important as extent of summer drawdown, then summation of the slopes should yield a large negative value. The following is a list of variables for small fishes, with the sum of the positive and negative slopes given in parentheses: black bass biomass (+0.13), largemouth bass biomass (+0.14), spotted bass biomass (-0.02), crappie biomass (+0.05), black crappie density (+0.05), and gizzard shad density (-0.13). For intermediate-size fish, results were as follows: sport-fish biomass (-0.01), green sunfish density (-0.03), white bass density (-0.15), and threadfin shad density (-0.14). Net slopes listed above probably do not differ significantly from zero, indicating that the two variables are approximately of equal importance. Note that the net effects for small fish were mostly positive, whereas those for intermediate-size fish were negative. This result probably reflects the importance of high spring water levels for reproduction and high summer water levels for survival.

Hydropower mainstream reservoirs

35. Independent variables reflecting seasonal or annual changes in water levels had only a few significant correlations to fish variables and therefore were eliminated from this discussion. Data on changes in area for the hydropower-mainstream data set were highly variable (Table 2), and this variability may account for the scarcity of correlations with fish variables. The few significant correlations are presented in Appendix B.

36. Important independent variables could not be ranked by the frequency of significant occurrence (at $\alpha = 0.05$) as was done with the hydropower storage data set because most variables had about the same number of occurrences. Independent variables, listed according to season of occurrence, with the number of significant equations given in

parentheses, were as follows: previous fall area (10), previous fall storage ratio (9), winter-spring area (10), spring area (8), spring storage ratio (8), and summer area (8).

37. Spring storage ratio and winter-spring and spring surface areas were the most important variables for producing above-average densities and biomass of small fishes in August (see Table 6). Spring storage ratio was a significant negative correlate to small fish variables in every case, indicating that above-normal rates of water exchange (inflow) in spring produce above-average densities and biomass of many types of small fish in August. Winter-spring and spring surface areas were positive correlates to fish variables in 93 percent of the significant correlations. An examination of groups of fish correlated (at $\alpha = 0.20$) with winter-spring or spring area and spring storage ratio (Table 6) further confirms that the reproductive success of many groups was increased by high inflow and above-average surface area. Above-average surface areas and low storage ratios in the previous fall apparently improved the reproductive success of sunfishes in the next spring, whereas the production of small catfishes benefited from low water in the previous fall. These results are similar to the findings for these groups of fishes in hydropower storage reservoirs, and most of the findings about effects of water-level changes on small fish in mainstream reservoirs support previous findings published in the literature for reservoirs in general.

38. Of all the independent variables, surface area in the previous fall was most often correlated to the biomass or density of intermediate-size fishes. Intermediate-size fish that were positive correlates to fall area are listed in Table 6. Eight of the nine significant correlations between area in the previous fall and fish variables in August were positive, indicating that above-average surface area in fall probably increases the survival of most of the fish that hatched the previous spring. Evidently, the extra space and refuge provided by high waters produce the same results on intermediate-size fish in mainstream reservoirs that they did in storage reservoirs. Intermediate pike density was the only variable that was inversely correlated to area in the

previous fall. Because YOY pikes grow to a larger size than most fishes and have secretive habits, they may be less susceptible to predation and may even benefit from reduced water levels that concentrate prey fishes.

Flood control reservoirs

39. Of the ten independent variables in this data set, only the seven that were correlated to a substantial number of fish variables will be discussed. Changes in area in the previous fall, spring, and per year were the poorest independent variables. Attempts to rank the seven remaining variables according to the number of significant correlates and consistency of effects were frustrated by the fact that those variables correlated to the most fish variables also had the most inconsistent effects on different types of fish. The variables finally were ranked according to their potential for manipulation and consistency of effects. They were as follows: (a) summer area, (b) fall storage ratio, (c) summer drawdown, (d) spring area, (e) spring storage ratio, (f) fall area, and (g) winter-spring area. Winter-spring and spring area are considered to be one variable in the following discussion of the effects of these seven variables on the fish community since their effects were similar. For simplicity, the effects of variables are discussed in chronological order by season rather than in the order they were ranked.

40. Storage ratio in the previous fall had a greater effect on fish in flood control and mainstream reservoirs than in hydropower storage impoundments. It was directly correlated with the density and biomass of intermediate-size sport fish, walleye, bluegills, and common carp, as well as the total density of reservoir fishes. This finding is consistent with those on relations between fall storage ratio and some of the fish variables in mainstream reservoirs but not in hydropower storage impoundments. Some YOY fish apparently are flushed from mainstream reservoirs when water in the reservoir is exchanged rapidly during storm events, or from flood control reservoirs where water can exchange in less than 2 months and extensive fall and summer drawdowns commonly reduce surface area by 60 percent.

41. Reduced water exchange rates and above-average area in the

previous fall apparently enhance the reproductive success of spotted bass, bluegills, and lepomid sunfishes the next spring (Table 7). Positive relations between previous fall area and the abundance of these fish the next August may be partially explained by the fact that above-average area in fall can dramatically increase the abundance of benthos (Benson and Hudson 1975). Young spotted bass and sunfishes feed extensively on benthos, and their survival could be increased if food were less limiting. The biomass of intermediate-size largemouth bass, black crappie, and sunfishes was increased after years in which area was higher than usual in fall, suggesting that survival of YOY fishes produced in the previous year was also increased. Negative correlation between previous fall area and the abundance of small crappies, small catfishes, and intermediate catfishes is generally consistent with findings for the other types of reservoirs, except that small crappies were positive correlates to this variable in mainstream reservoirs.

42. Except for small crappies, which were inversely correlated to previous fall area, above-average surface area in fall, spring, and summer resulted in increased biomass and density of most small and intermediate-size centrarchids, temperate basses, and sport fishes (excluding catfishes) in August (Table 7). Above-average surface area in spring increased the abundance of sport fishes of all sizes while reducing the total density of reservoir fishes. Reduced total densities reflect the apparent negative effect of high spring area on non-sport fishes, which comprise most of the total number and biomass of fish in reservoirs.

43. The most unexpected finding was that the abundance of some groups of small and intermediate-size fish was inversely correlated with surface area in spring (Table 7). Most of these fish could be classified either as commercial fish (e.g., catfishes, buffalofishes, freshwater drum, and common carp) or as forage fish (gizzard shad, carpsuckers, and minnows). Inverse correlations between the abundance of these groups of fish and spring area contradict previously published information. For example, Benson (1973) reported that the reproduction of common carp, river carpsuckers, and buffalofishes was improved by

rising or stable water levels over suitable substrates such as terrestrial vegetation in the large Missouri River hydropower reservoirs. Walburg (1976) reported that spawning success of some species such as freshwater drum and channel catfish was unaffected by wide fluctuations in water levels in Lewis and Clark Lake, South Dakota, while that of nearshore spawning fishes such as gizzard shad and emerald shiners (a species of minnow) was adversely affected by low and variable water levels from 1 March to 15 July. Increased survival of small prey fishes, which would be required to produce above-average crops of intermediate-size fish, has almost always been associated with high water in spring and occasionally summer because it provides more space and refuge in flooded vegetation or other structures (Murdock and Oaten 1975; Cooper and Crowder 1979). However, results here suggest that survival of prey fishes in flood control reservoirs is increased by below-average surface areas in spring and summer (Table 7).

44. Correlations between spring and summer area and the abundance of commercial and prey fishes were not the only evidence found that these groups of fish apparently were more successful when spring inflows were below normal (spring storage ratio was inversely correlated to area) and when summer drawdown was extensive. Small catfishes and freshwater drum also were positive correlates to spring storage ratio and summer drawdown, and intermediate-size common carp and the total density of intermediate-size reservoir fish (all species) were positively affected by low rates of water exchange. In contrast, intermediate-size sport fish, black basses, largemouth bass, and sport fish of all sizes were more abundant when the extent of summer drawdown was reduced.

45. There are four possible explanations for the divergent results presented in the previous paragraphs.

a. Apparent changes in the biomass or density of fishes listed as negative correlates to spring and summer area (Table 7) may have resulted from physical constriction or expansion of available area. In these flood control reservoirs, the mean spring change in area was highly variable, and the maximum change in area per year averaged 88 percent of the mean surface area. There is a distinct possibility that extremely low water in August of some years concentrated reservoir fish, giving some groups the appearance of a positive response (increased biomass or density). For example, fish that were not affected by changes in water levels (perhaps catfishes or freshwater drum) but nevertheless were concentrated in one-half the normal August surface area would appear to be twice as abundant as the same number of fish in a reservoir with normal August surface area. On the other hand, low water in spring and summer may be so detrimental to the reproductive success of certain sport fishes (e.g., largemouth bass or crappies) that even the concentrating effect of low water could not make the low density of small fish appear to be higher than in high-water years, when their reproductive success would be greatly enhanced.

b. Most of the fishes that appeared to benefit from low spring and summer areas (Table 7) are benthos feeders and could benefit by being in proximity to established benthic food sources. Benthic organisms often exhibit inverted vertical distributions in widely fluctuating reservoirs (Grimas 1961; Kaster and Jacobi 1978). Above-average water levels in spring and summer could temporarily separate the strictly benthophagous fish from their food and thereby reduce their survival.

c. Some commercial and prey fish may fare better in low water than in high water because piscivores are generally much more successful in high-water years. In this study of flood reservoirs, inverse correlations between small prey fishes and intermediate-size sport fishes were common.

d. Reservoir water quality during drought conditions may, in an as yet unknown fashion, favor commercial and rough fish. The reservoir would warm more quickly, stratify earlier, and nutrient inputs and turbidity would be below average. The above factors may shift the competitive balance from sport fish to commercial and rough fish.

46. Management of flood control reservoirs offers a unique opportunity for increasing sport fish production at the expense of commercial and forage fishes if the changes in fish biomass or density reflect actual changes in fish populations. Correlations in Table 7 suggest that above-average surface area in spring will increase the reproductive success of most sport fishes. Summer and fall ar s should be kept as high as possible (maintain a seasonal conservation pool) to produce a successful year class. This recommendation is well substantiated by

the literature and the data collected in this investigation. However, before management plans are developed to "increase" the production of commercial fishes by maintaining low water levels in spring and summer in flood control reservoirs, further research should be conducted to ensure that the apparent benefit observed was not just a result of concentrating fish.

Effects of Water Level Fluctuations on Specific Groups of Fish

47. Multiple regression equations in Appendices A, B, and C indicate how combinations of hydrologic variables affect species or groups of fish in each of the three types of reservoirs. These equations can be used to identify the specific aspects of reservoir operation that affect the reservoir fishery. The effects of major alterations in reservoir operation on the inpool fishery can be quantified if seasonal changes in water level can be predicted. For example, the impacts of seasonal water-level changes associated with the addition of hydropower generating capability can be quantified. Additionally, these equations, in conjunction with consultations with state and Federal fishery personnel, can be used to design well-documented management plans that protect or even enhance the reservoir fishery under existing reservoir operation procedures. The scope here was limited to discussion of effects of fluctuating water levels on important sport fishes in the three types of reservoirs, though effects could be identified for other groups of fish using the same regression equations.

Hydropower storage reservoirs

48. Effects of water-level changes outlined here for storage reservoirs were derived from regression equations in Appendix A.

49. As an entity, sport fishes of all sizes responded favorably to an above-average increase in surface area from March to May and to a mean surface area above normal in spring and summer. These findings do not necessarily mean that all species that comprise the collective group "sport fish" respond in the same way. It could mean that a few species that compose most of the numbers and biomass exhibit similar responses (sport fishes in the storage reservoirs were dominated by centrarchids).

During a wetter-than-normal year, the production of small sport fishes should be increased if more water were discharged in fall (reduced fall storage ratio) and if spring inflows were stored (above-normal spring storage ratios), thereby creating a larger than average surface area in spring. Survival of intermediate-size sport fish can be increased by reducing summer drawdown and maintaining above-average surface area in summer. Thus, if the above water-level conditions produced more small sport fish than usual in the previous year, maintenance of a high summer pool in the current year will enhance the survival of yearling sport fish.

50. Findings for largemouth bass were similar to those for sport fish variables. Equations for predicting the biomass or density of small largemouth bass suggest that reproductive success will be increased by the following hydrologic regime: (a) water is released more rapidly than usual in fall (during a wet fall) and the extent of drawdown is increased, (b) below-average area in fall is maintained to permit the development of terrestrial vegetation in the drained zone, (c) water is retained in spring (above-average storage ratio) to make the average surface area in spring exceed the mean for the reservoir, and (d) water levels are kept above the average summer pool throughout summer. This regime is essentially identical to that most often proposed by fishery biologists (Keith 1975; Groen and Schroeder 1978). Intermediate-size largemouth bass also benefit from such a water-level regime (see equations in Appendix A).

51. Multiple regression equations relating spotted bass variables to combinations of seasonal hydrologic variables show that a hydrologic regime similar to that for largemouth bass would be beneficial (Appendix A). The only difference is that drawdown in the previous fall should be limited to benefit small spotted bass produced the next year, while intermediate-size spotted bass appear to be more successful when drawdown in the previous fall was large. The differences in responses of YOY and yearling spotted bass, as well as YOY largemouth bass, could be due to the differing survival resulting from the availability of different foods. Studies by the NRRP staff have shown that YOY spotted

bass are primarily benthos feeders, whereas many intermediate spotted bass are piscivorous and YOY largemouth bass eat zooplankton. Fall drawdowns in the previous year have been shown to adversely affect benthos populations the following spring (Benson and Hudson 1975) and thus could impair the food supply of YOY spotted bass without being detrimental to that of intermediate-size spotted bass or YOY largemouth bass. In fact, zooplanktivores and piscivores (YOY largemouth bass and yearling spotted bass, respectively) should benefit from increased zooplankton and forage-fish production. Such increased production normally occurs after spring flooding of terrestrial vegetation established the previous fall.

52. Water-level requirements for smallmouth bass differ somewhat from those for largemouth and spotted basses. Similar conclusions were made by Aggus (1979). Drawdown in fall reduced the biomass of small smallmouth bass in August of the next year, and large annual changes in surface area were detrimental. Small smallmouth bass are benthophagous, and a reduction in benthic food resources by a drawdown in fall may reduce the carrying capacity of littoral areas the next spring. The response of small smallmouth bass differs from that of small largemouth bass, though it is similar to that of small spotted bass. In other ways, however, responses of smallmouth bass are similar to those of spotted and largemouth bass. The biomass and density of small smallmouth bass can be increased by large increases in water level from March to May and by maintaining somewhat higher water levels in spring and summer than in the rest of the year.

53. Reproductive success of white crappie reportedly has been increased in reservoirs where water levels were low in fall and high in spring (Benson 1976; Fourt 1978; Groen and Schroeder 1978). However, in this study no significant correlations were obtained, probably because of inconsistent sampling of small and intermediate-size white crappie in coves. Biomass and numbers of small black crappie and small crappies (both species combined) were significantly correlated with hydrologic variables, but no correlations were obtained for intermediate-size crappies, which fact suggests hydrology may have a greater effect

on the reproduction of crappies than on their post-hatching survival or, alternatively, intermediate crappies may not be adequately sampled in coves. Successful reproduction of crappies requires reduced pool levels in late summer or fall of the previous year, and above-average levels from 1 February to 31 May. Fall drawdown would permit recolonization or seeding of herbaceous vegetation in the drained zone. Flooded, fibrous vegetation is the preferred spawning habitat for black crappie.*

54. Not all of the lepomid sunfishes responded in exactly the same way to hydrologic regimes in storage reservoirs, but responses were similar. Densities of small sunfishes were high when water exchange rate was below average in spring and changes in area in summer and throughout the year were above average (Appendix A). Apparently many lepomids have better reproductive success in years when hydrology is less favorable for reproduction by most other species. In contrast to reproduction by largemouth bass, spotted bass, or crappies, the production of YOY sunfish does not appear to be enhanced by drawdowns in the previous fall or by spring flooding in storage reservoirs. However, the biomass of intermediate-size lepomids was positively correlated with spring area and spring flooding.

55. Existing intermediate-size sunfishes may periodically take advantage of the improved trophic conditions (increased invertebrate production and spawn from other species--sunfish are notorious egg predators) when water levels are high. If high water levels actually enhance the survival of the previous year's YOY, then water levels that benefit the reproduction of other important sport fish should also increase the biomass of large sunfishes.

56. Reproduction by white bass is seldom affected by water-level changes in reservoirs because white bass usually spawn in tributaries (Benson 1973). In this analysis, no significant correlations were obtained between small white bass and hydrologic variables. However, the density of intermediate-size white bass in August was above average in

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* Personal Communication, 22 Feb 1983, L. E. Vogele, Fishery Biologist, National Reservoir Research Program, Fayetteville, Ark.

years when spring water levels were high and the magnitude of summer drawdown was below normal (Appendix A). As with many other yearling piscivores, survival and growth of yearling white bass probably is improved by above-average surface area in spring and summer because the abundance of many forage fishes is increased.

57. The density of small yellow perch in August was correlated only with summer area. The relation was positive, suggesting that recruitment is limited by survival of YOY after they hatch in spring. Consequently, their reproductive success would be improved by above-average water levels in summer. The detrimental effect of summer drawdowns on littoral benthos, the primary food of young yellow perch (Scidmore and Woods 1960), has been well documented (Cowell and Hudson 1967; Kaster and Jacobi 1978).

58. Although channel catfish reproductive success was not affected by water levels in Lewis and Clark Lake (Walburg 1976), significant correlations were obtained in this study (Appendix A). Equations derived suggest that channel catfish reproduction is enhanced by below-average changes in surface area throughout the year, especially in summer when the extent of drawdown should be reduced. Beneficial changes in pool levels include somewhat lower than average levels in fall and above-average levels in early spring.

59. Small flathead catfish responses were similar to those of small channel catfish. Their biomass was highest in years following ones with below-normal water levels in fall. Years of successful reproduction were characterized by below-average annual changes in surface area, with above-average increases in surface area in spring. Reduced annual changes in area with above-average spring flooding could occur only if summer and fall drawdowns were reduced. Relatively stable water levels with some spring flooding evidently improve flathead catfish reproduction and survival.

Hydropower mainstream reservoirs

60. Outlines of potentially beneficial hydrologic regimes for sport fishes in mainstream reservoirs were developed from regression equations in Appendix B. In mainstream reservoirs, the overriding

influence of inflow on water levels limits the amount of manipulative control that can be exercised. Therefore, outlining beneficial regimes may not be of as much value for management as illustrating typical responses of sport fish to natural sequences of flooding and seasonal hydrology in large river-like reservoirs.

61. The density of sport fish as a single entity was higher in years when annual changes in area and winter-spring area were above average. Equations in Appendix B on the density of small sport fish suggest that strong year classes would be most likely to develop if spring inflows were heavy (storage ratio was low), the total change in area per year was large, and reductions in surface area in the previous fall were below normal. Equations in Appendix B also suggest that the recruitment of most sport fish, or of at least the few dominant groups, was enhanced by flooding. Centrarchids (mostly sunfishes) comprised 50 percent of all sport fishes.

62. Regressions of the biomass or density of small largemouth bass (dominant black bass) were similar to those for small sport fish except that an additional variable was included. Above-average increases in surface area between March and May resulted in above-average biomass and densities of small largemouth bass in August. Equations for intermediate-size largemouth bass suggest that the survival of young fish was increased by high water in the fall, early spring, and spring. Although spotted bass were poorly represented in the data set on mainstream reservoirs, above-average surface area and flow in the previous fall also were important to the survival of young spotted bass (Appendix B). Data on smallmouth bass were inadequate, and no regression equations were derived.

63. The response of crappies to hydrologic variables was similar to that of largemouth bass. The reproductive success of white crappies apparently was increased by rapid water exchange (flow) in spring and above-average area in early spring. The biomass of yearling white crappie in August was high after years when water elevations were above average in fall. Small black crappie biomass was highest in years when changes in surface area were greatest in spring (flooding) and summer

(receding water). Increased inflows and exchanges of water in spring also were beneficial.

64. Responses of different species of sunfishes were more diverse in mainstream than in storage reservoirs. The abundance of small sunfishes (70 percent were bluegills) was above average in years when change in area per year and spring inflow (water exchange rate) were high. In addition, their density was above normal when area in the previous fall had been stable and above average. Warmouth reproduction was enhanced by above-average changes in area each year, but with extensive reduction in surface area in the previous fall and substantial spring flooding. Reproduction of redear sunfish was improved by low flow and above-normal drawdown in the previous fall.

65. The abundance of small temperate basses and white bass was positively correlated with the surface area in spring. Survival of young fish after hatching and during their first 1.5 years apparently was improved by above-normal area in fall and below-average area and flow in the following spring. However, survival was increased by above-average area in summer. Temperate basses seem to benefit from natural seasonal fluctuations in water levels in much the same way as most other groups (see Keith 1975 for a description of typical responses).

66. The abundance of intermediate-size sauger in August was correlated with low rates of water exchange and surface area in the previous fall and in spring. Low water levels in spring may concentrate prey fishes for the highly piscivorous yearlings and thereby increase their survival.

67. Small catfishes were more abundant in August when waters were reduced less than normal in the previous fall and in years when summer area was below average. The biomass of small catfishes was correlated with above-average reductions in surface area in summer. These results contradict findings for small catfishes in storage reservoirs but agree fairly well with those for flood control reservoirs. Intermediate-size channel catfish biomass was higher following years with above-average surface area in fall; intermediate-size flathead catfish biomass was above average in years after surface area had

increased more than usual between March and May. The hypothesis that high water enhances the survival of young fish by providing more habitat and food seems to be a reasonable explanation for these observations.

Flood control reservoirs

68. The responses of sport fishes to hydrologic changes in flood control reservoirs were developed from regression equations in Appendix C. Most sport fish were in the centrarchid family.

69. Findings for sport fish in flood control reservoirs are similar to those for the other reservoir types, except that the effects of the extreme annual changes in area are more apparent in flood control reservoirs than in the others types of impoundments. The total biomass of sport fish was directly correlated with summer area and previous fall storage ratio, and density was inversely related to maximum change in area per year (Appendix C). These variables are related to some extent since an increase in fall area (decrease in drawdown) would reduce the extent of annual change in area, which must adversely impact fish by reducing carrying capacity and benthic food resources in late summer or fall. Of the five reservoirs in the flood control data set, only one (Barren River Reservoir, Kentucky) was operated to maintain a summer conservation pool by delaying drawdown until late fall. Clearly, reproductive success is enhanced by maintaining above-average surface area in the previous fall, spring, and summer. In addition, reduced annual changes in area would be beneficial, but this should occur automatically if area was kept above average in fall, spring, and summer. The equation for predicting the biomass of intermediate-size sport fish suggests that survival of YOY is increased when discharge (water exchange rate) is reduced in fall during a dry year. Below-average water levels in early spring, followed by above-normal inflow and water exchange rates from March to May and a high summer conservation pool, would reduce the mortality of most yearling sport fish.

70. Equations for predicting the abundance of small black basses and largemouth bass were not significant, and those for small spotted bass did not include enough different kinds of hyrologic variables for analysis. Intermediate-size largemouth bass abundance is apparently

enhanced by decreased drawdown and maintenance of a higher pool level in the fall. The rate of discharge of water should be reduced in fall if the reproductive success of largemouth bass was successful the previous spring. The next spring, if inflows are appropriate, pool levels should be increased slowly and held at above-average levels during summer; total yearly fluctuations should be kept below average. Intermediate-size spotted bass also appear to benefit from reduced drawdowns in summer.

71. The abundance of small crappies in August (a reflection of reproductive success) would be increased if annual fluctuations were dampened, fall area were reduced below average, and the reservoir slowly filled in spring to reach and maintain above-average spring water levels. Small black crappies tend to be more abundant if summer drawdown is less than usual. Survival of young crappies was higher when water levels fluctuated more extensively. For white crappie, higher than average water levels in summer were important for increasing survival, as indexed by the abundance of intermediate-size white crappie in August. Survival of YOY black crappie was increased by high water in fall; yearlings appeared to benefit from low water in spring. However, the absence of other significant equations precluded further insight into effects on intermediate-size black crappie.

72. Of the lepomid sunfishes in the flood control sample, 85 percent were bluegills, 8 percent were green sunfish, and 6 percent were warmouth (Appendix D). Small bluegills were more abundant in years when storage ratio and surface area in the previous fall had been above normal and when early spring water levels were high. The high water in the previous fall would have kept the littoral benthos intact and thereby provided a more stable benthic food supply for YOY bluegills. High water in spring may enhance reproduction by providing more and better spawning sites and could increase zooplankton production. Young bluegills apparently survived better after a drawdown in the fall and flooding in spring. Low water in fall could allow herbaceous vegetation to develop, and after being flooded in spring, vegetation would provide more refuge from predators. Reproductive success of green sunfish was

improved by increased water exchange rates and above-average surface area between March and May, after below-average water levels in February and March. Reduced annual change in area was beneficial to green sunfish and warmouth.

73. The few significant regression equations for predicting small and intermediate-size white bass biomass or density (Appendix C) were poor and barely significant at $\alpha = 0.05$. However, the equation for intermediate white bass suggests that survival of young white bass can be increased by extensive fall drawdown and maintenance of above-average area the next summer. This result is fairly consistent with observations for the other types of reservoirs and prevailing hypotheses in the literature.

74. In flood control reservoirs, the abundance of small channel catfish was higher when maximum change in area per year was less than usual and when surface area was below average in spring and summer. By contrast, in storage reservoirs, successful reproduction was related to above-average drawdown in the previous fall, higher than normal area in spring, and reduced changes in area in summer and throughout the year. Possible explanations for the different responses in the two types of reservoirs were discussed in the section "Effects of Individual Hydrologic Variables on Fish," under the subheading "Flood control reservoirs." Further research is needed on these apparent responses before definite management plans can be developed. Intermediate-size channel catfish density was high in years when annual changes in area were lower than usual. This fact suggests that stable water levels increase the recruitment of channel catfish, a suggestion supportive of findings for the other types of reservoirs.

75. Flathead catfish reproduction was enhanced by high rates of water exchange in the previous fall (higher than normal rates of water release) but low rates in spring (low inflow). Their recruitment, as indicated by the abundance of intermediate-size flathead catfish, apparently is increased in years when spring flooding and surface area are higher than average, but when summer drawdown is more extensive than usual.

Predictive Techniques

76. Equations listed in Appendices A (hydropower storage), B (hydropower mainstream), and C (flood control) can be used to predict the effects of existing or proposed water-level regimes. However, because both the hydrologic and fishery variables were converted to standard normal deviations ($\underline{Z}$ scores) for regression analyses, water exchange and areal variables in the reservoir being investigated must first be converted to $\underline{Z}$ scores. Standard normal deviations in fish biomass or density can then be predicted from appropriate regression equations. To evaluate fully the extent of changes in biomass or density, the predicted deviations must be converted to kilograms/hectare (biomass) or numbers/hectare (density). Identical $\underline{Z}$ scores can represent radically different values if the means and standard deviations from which they are calculated differ greatly.

77. The formula for transforming data to $\underline{Z}$ scores is

$$Z = \frac{X - \bar{X}}{SD} \tag{1}$$

where

$Z = \underline{Z}$ score

X = variable to be transformed

$\bar{X}$ = mean of variable X

SD = standard deviation of variable X

Means and standard deviations of independent hydrologic variables in the three data sets are presented in Table 2. As an example, suppose average spring surface area for hydropower storage reservoirs was raised 500 ha above the mean given in Table 2 (24,383 ha); then, according to Equation 1, the associated $\underline{Z}$ score would be (24,883 - 24,383)/1,354 = 0.37. Conversely, if average spring area were reduced 500 ha below the mean in Table 2, the $\underline{Z}$ score would be (23,883 - 24,383)/1,354 = -0.37. The regression equation from Appendix A

$$\text{small largemouth bass biomass} = -0.076 + 0.614\ (\text{SPA}) \tag{2}$$

where

small largemouth bass biomass = the $\underline{Z}$ score for biomass of small largemouth bass

-0.076 = intercept of regression equation obtained from Appendix A, page A5

0.614 = regression coefficient obtained from Appendix A, page A5

SPA = spring surface area

can be used to estimate the $\underline{Z}$ score for fish biomass for a particular seasonal surface area. The $\underline{Z}$ score for small largemouth biomass under average conditions could be calculated by using a $\underline{Z}$ score value of 0.0 for SPA in Equation 2, yielding a value of -0.076. If a $\underline{Z}$ score of 0.37 for SPA were substituted into Equation 2, the predicted $\underline{Z}$ score for small largemouth bass biomass would be 0.15, indicating that raising the average area in spring by 500 ha would increase the small largemouth bass biomass $\underline{Z}$ score from -0.076 to 0.15.

78. A $\underline{Z}$ score is converted to biomass or density original units by:

$$X = (Z \times SD) + \bar{X} \tag{3}$$

where

X = predicted first biomass or density

Z = predicted Z from Equation 2

$\bar{X}$ = mean of fish biomass or density from Appendix D

SD = standard deviation of fish biomass or density from Appendix D

Means and standard deviations for fish variables in the three types of reservoirs are given in Appendix D. For example, a $\underline{Z}$ score of -0.076, predicted for small largemouth bass biomass if spring area were average ($\underline{Z}$ = 0, previous paragraph), can be converted to biomass (kilograms/hectare) by using Equation 3 and the $\bar{X}$ and SD for small largemouth bass biomass from Appendix D (e.g. biomass = (-0.076 × 2.10) + 1.30 = 1.14 kg/ha). Hence, with an average spring area, small largemouth bass biomass should be about 1.14 kg/ha. Converting the $\underline{Z}$ score 0.15, predicted assuming spring area was 500 ha above normal, into biomass (i.e.,

$(0.15 \times 2.10) + 1.30)$ produces 1.62 kg/ha. Therefore, increasing surface area 500 ha above normal in spring increased the biomass of small largemouth bass in August by 0.48 kg/ha (1.62 - 1.14), or 42 percent.

79. The effects of hydrologic variables (i.e., effects of reservoir operation) on fish biomass and density can be explored by examining predictions when all independent variables are at average conditions. Standard normal deviations in fish biomass or density can be predicted for average conditions by substituting zero for independent terms in the regression equations in Appendices A, B, and C. Predicted $\underline{Z}$ scores should then be converted to kilograms/hectare or numbers/hectare. The next steps would be to vary the means of hydrologic variables in Table 2 and then develop reasonable proposed regimes of operation. After transforming proposed values to $\underline{Z}$ scores, they should be substituted into regression equations in Appendix A, B, or C to predict $\underline{Z}$ scores for fish biomass or density. Effects of alternative hydrologic regimes can then be evaluated after converting predicted $\underline{Z}$ scores to kilograms/hectare or numbers/hectare.

80. An alternative method of examining the effects of hydrologic variables on fish would be to collate at least 4 years of hydrologic data from a reservoir and calculate means and standard deviations for every hydrologic variable. Next, $\underline{Z}$ scores for proposed changes in hydrologic variables should be calculated from the means and standard deviations and substituted into regression equations in Appendix A, B, or C, depending on the type of reservoir involved. After predicting $\underline{Z}$ scores for fish variables under the existing and proposed hydrologic regimes and converting these results to kilograms/hectare or numbers/hectare, the effects of the different operational alternatives should be compared and evaluated. If at least 4 years of fish data also were available from the reservoir, then predicted $\underline{Z}$ scores for fish could be converted to kilograms/hectare or numbers/hectare using calculated means and standard deviations for fish in that reservoir.

PART IV: CONCLUSIONS

81. Results presented in this paper illustrate why water-level changes are widely considered to have such a significant impact on reservoir fisheries. Although the exact response mechanisms vary somewhat among species, effects of water-level changes on many fishes can be predicted with relatively simple regression equations. These equations can then be used by a biologist or engineer to estimate the effects on the reservoir fishery of altering seasonal water levels amd reservoir operations in existing and proposed reservoirs. Additionally, these predictions can be used as guidelines to protect or enhance reservoir fisheries.

82. This report details findings of multiple regression analyses relating fish variables to seasonal hydrologic variables in three types of reservoirs (hydropower storage, hydropower mainstream, and flood control). Correlations were used to rank seasonal hydrologic variables according to their importance for fisheries and to outline management strategies for important species or assemblages of fish. Regression equations for three types of reservoirs (Appendices A-C) form the basis for a quantitative predictive methodology for evaluating effects of existing or proposed reservoir operational regimes on fish reproductive success and recruitment.

83. Hydrologic variables in hydropower storage reservoirs were the most consistent in terms of positive and negative effects on different fish, and effects were most consonant with prevailing hypotheses in the literature. More significant equations were obtained from this data set than from the others, probably because the sample was large (25 reservoir-years of data) and the most homogeneous with regard to morphometry, seasonal patterns of operation, and fish composition and abundance. The abundance of many fish in August was positively correlated with each of the four most important independent variables (i.e., mean spring area, annual change in area, mean summer area, and spring change in area). Above-average summer drawdowns usually resulted in below-average fish abundance in August. Results strongly suggest that

reduced survival after hatching is more limiting to fish recruitment than poor spawning success in spring. Once every 3 to 5 years, attempts should be made to (a) draw down water levels in late summer or fall and establish terrestrial vegetation in the fluctuation zone, (b) flood vegetation in spring, and (c) maintain above-average surface area for as much of the growing season as possible.

84. Although relations between hydrologic variables and fish abundance in hydropower mainstream reservoirs were generally similar to those obtained for hydropower storage reservoirs, they were of less value for management and prediction than for illustrating responses of fish to river-like conditions. Hydrology in hydropower mainstream reservoirs is highly variable and clearly forced by variations in runoff or storm events. Extensive flows and limited capacity for storing water cause water-level variables to fluctuate more frequently though less extensively than in the other types of reservoirs. The overriding influence of flow on water levels in mainstream impoundments limits the amount of manipulative control that can be exercised for management purposes. Regression equations suggest that management plans similar to those outlined for hydropower storage reservoirs will improve fisheries but to a lesser extent.

85. Regression equations derived from the flood control data were the least consistent or significant because of the heterogeneity of the reservoirs involved. The five impoundments in the data set varied widely in size, seasonal patterns of operation, and fish composition and abundance. However, high annual variability in fish abundance and the high degree of operational control possible in flood control reservoirs strongly suggest that water-level management could improve fisheries more than similar management in other types of reservoirs. Reproductive success and survival of most important fish apparently was increased by above-average surface area in spring, summer, and fall, but extensive annual changes in surface area had a negative impact on sport-fish abundance. Recommended management involves periodically (every 3 to 5 years) implementing a plan as outlined above for hydropower storage reservoirs. Most importantly for flood control reservoirs, large summer drawdowns

should be reduced or eliminated in favor of a relatively high conservation pool with evacuation of storage postponed until winter.

86. The scarcity of quantitative data collected for 4 or more consecutive years from one reservoir is perhaps the greatest hindrance to statistical verification of cause-effect hypotheses that surpass simple testing for positive or negative effects. The previous research on water levels was essential to the development of the testable hypotheses available today. But, only by examining long-term data sets can 2- or 3-year management operations be replicated and statistically examined to determine which elements of management plans were essential to success. Additionally, these kinds of data allow for predictions that are essential in evaluating requests for altered reservoir operations.

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Table 1

Physical, Chemical, and Morphometric Characteristics of Reservoirs in the Three Samples

Sample	Years of Physical and Biological Data	Reservoir, State	Year Impounded	Drainage Area km^2	Surface Elevation, m, above Mean Sea Level	Average Annual Surface Area ha	a/ Storage Ratio years	Mean Depth m	Maximum Depth m	Vertical Fluctuation m	b/ Shoreline Development Index	c/ TDS mg/ℓ	d/ Growing Season days
Hydropower mainstream	72-73, 78-81	Jackson, Ga.	1910	3,626	162	1,725	0.09	6.7	19.8	1.2	14.0	55	220
	75-80	Melton Hill, Tenn.	1963	8,658	242	2,128	0.02	6.4	20.4	0.8	11.3	125	200
	74-75, 77-78, 80	Old Hickory, Tenn.	1956	30,096	136	8,936	0.02	5.8	22.3	0.9	20.9	115	200
Hydropower storage	72-81	Bull Shoals, Ark.	1951	15,672	199	18,959	0.70	19.8	61.3	4.9	24.8	150	200
	60-64, 66-67, 76, 79	Clark Hill, Ga.	1952	15,929	101	28,477	0.42	10.4	43.9	2.4	28.6	55	230
	74-79	Kerr, Va.	1953	4,610	92	20,615	0.29	8.8	34.1	3.4	23.9	70	205
Flood control	78-81	Barren, Ky.	1964	2,435	168	3,737	0.24	7.9	24.1	8.2	10.0	140	190
	72-77	Grenada, Miss.	1954	3,419	63	14,012	0.26	4.6	18.9	8.2	6.6	40	231
	78-81	Lovewell, Kans.	1957	894	482	997	1.09	3.7	9.1	2.1	4.4	475	170
	77-79	Rathbun, Iowa	1969	1,422	276	4,457	0.92	5.8	15.8	3.4	12.2	250	172
	72-77	Sardis, Miss.	1940	4,002	76	13,644	0.21	5.8	21.6	6.1	5.2	35	217

a/ Storage ratio = average annual volume/total annual discharge.
b/ Shoreline development index (D) = shoreline length/$2\sqrt{\pi} \cdot$ area.
c/ TDS = total dissolved solids.
d/ Growing season = frost-free days/year.

Table 2

Independent Variables, Their Abbreviations, Definitions, and Means and Standard Deviations for the Data on Hydropower Storage, Hydropower Mainstream, and Flood Control Reservoirs. (Surface Area is in Hectares and Monthly Storage Ratios Indicate the Number of Months Required to Replace the Volume of an Average Impoundment.)

Variable	Abbreviation	Definition	Hydropower Storage Reservoirs (Mean ± SD)	Hydropower Mainstream Reservoirs (Mean ± SD)	Flood Control Reservoirs (Mean ± SD)
Fall storage ratio	FSR	Mean of monthly storage ratios in Sep and Oct (previous year)	7.6 ± 3.5	1.0 ± 0.4	5.8 ± 3.9
Fall change in area	dA8-10	Difference in surface area on 31 Jul and 31 Oct (previous year)	-1,685.9 ± 1,901.3	-184.6±231.7	-3,353.8 ± 1,156.8
Fall area	FA	Mean of surface areas measured on 31 Aug, 30 Sep, and 31 Oct (previous year)	22,968.6 ± 1,297.9	4,186.0±120.2	7,073.1 ± 1,301.5
Winter-Spring area	WSA	Mean of surface areas measured on 31 Jan, 28 Feb, and 31 Mar	23,760.1 ± 1,680.1	4,186.0 ± 97.7	8,545.0 ± 1,920.6
Spring storage ratio	SPSR	Mean of monthly storage ratios in Mar, Apr, and May	6.4 ± 3.7	0.4 ± 0.[illegible]	9.8 ± 5.4
Spring change in area	dA3-5	Difference in surface area on on 28 Feb and 31 May	1,141.6 ± 2,231.8	46.8 ± 182.4	2,515.2 ± 1,458.3
Spring area	SPA	Mean of surface areas measured on 28 Feb, 31 Mar, 30 Apr, and 31 May	24,382.6 ± 1,354.0	4,315.5 ± 87.2	9,706.7 ± 1,656.9
Summer change in area	dA6-8	Difference in surface area on 31 May and 31 Aug	-1,270.0 ± 1,333.6	-74.9 ± 131.5	-2,171.1 ± 710.3
Summer area	SUA	Mean of surface areas measured on 31 May, 30 Jun, 31 Jul, and 31 Aug	24,173.8 ± 1,371.5	4,301.7 ± 84.3	9,590.8 ± 1,489.2
Annual change in area	dA/yr	Maximum difference in area per year	5,241.9 ± 2,103.1	588.2 ± 216.2	6,503.2 ± 1,547.6

Table 3

Significant ($p < 0.05$) Pearson Product Moment Correlation

Coefficients of Independent Variables

for the Study Reservoirs a/

Hydropower Storage Reservoirs

	b/ SPSR	SPA	SUA	FSR	FA	da/YR	dA3-5	dA6-8	dA8-10
WSA	-0.57	0.92	0.43	--	--	--	--	--	--
SPSR		-0.70	-0.40	--	--	--	--	--	--
SPA			0.54	--	--	--	--	--	--
SUA				--	0.34	--	--	--	--
FSR					-0.31	--	--	--	--
FA						-0.44	--	0.38	0.31
dA/YR							0.42	-0.57	--
dA3-5								-0.62	--
dA6-8									--

Hydropower Mainstream Reservoirs

	SPSR	SPA	SUA	FA	dA3-5	dA6-8	dA8-10
WSA	-0.61	0.80	0.46	--	--	--	--
SPSR		-0.44	--	--	--	--	--
SPA			0.50	--	--	--	--
SUA				--	--	--	--
FA					--	--	0.59
dA3-5						-0.45	--
dA6-8							--

Flood Control Reservoirs

	SPSR	SPA	SUA	FA	dA/YR	dA3-5	dA6-8
WSA	-0.67	0.89	0.36	--	--	-0.50	--
SPSR		0.67	--	-0.40	--	0.37	--
SPA			0.50	--	--	--	-0.40
SUA				0.35	0.31	--	--
FA					0.39	--	--
dA/YR						--	-0.47
dA3-5							--

a/ Definitions of variables are given in Table 2.

b/ Only variables with at least one significant correlation coefficient are included.

Table 4

Fish Variables in Hydropower Storage Reservoirs That Were Correlated at $\alpha = 0.05$ with Average Surface Area in Fall, Winter-Spring or Spring, and Summer[a]

Fall Area (previous year) Negative Correlates		Winter-Spring or Spring Area Positive Correlates		Summer Area Positive Correlates	
		Small Fishes			
Spotted bass	(N)	All species	(B)	All species	(B)
Smallmouth bass	(N)	Sport fishes	(B)	Black basses	(B,N)
Crappies	(B,N)	Black basses	(B)	Largemouth bass	(B,N)
Black crappie	(B,N)	Largemouth bass	(B,N)	Spotted bass	(B)
Catfishes	(B,N)	Spotted bass	(B)	Black crappie	(N)
Channel catfish	(B)	Crappies	(B,N)	Yellow perch	(B,N)
Flathead catfish	(B)	Black crappie	(B,N)	Threadfin shad	(B)
Gizzard shad	(N)	Gizzard shad	(N)		
		Intermediate-Size Fish			
Black basses	(N)	Black basses	(B,N)	Sport fishes	(B)
Largemouth bass	(N)	Largemouth bass	(B,N)	Black basses	(B)
		Lepomid sunfish	(B,N)	Largemouth bass	(B)
		Bluegill	(B,N)	Lepomid sunfish	(B,N)
		Warmouth	(B)	Bluegill	(B,N)
		Green sunfish	(B,N)	Green sunfish	(B)
		Temperate basses	(N)	Redhorses	(B,N)
		White bass	(N)		
		Common carp	(B,N)		
		Redhorses	(B,N)		
		Threadfin shad	(B,N)		
		All Size Fishes			
		Sport fishes	(B)	All species	(B,N)
				Sport fishes	(N)
				Golden shiner	(B)
				Minnows	(B,N)

NOTE: The few correlates that had inverse relations to those shown here are discussed in the text.

a/ Unit of variable (noted in parentheses) is B (biomass) or N (number).

Table 5

Fish Variables in Hydropower Storage Reservoirs That Were Correlated at $\alpha = 0.05$ (Unless Indicated Otherwise) to Changes in Surface Area in Fall, Spring, and Summer[a/]

Fall Drawdown (previous year) (dA8-10) Positive Correlates		Spring Flooding (dA3-5) Positive Correlates		Summer Drawdown (dA6-8) Negative Correlates	
		Small Fishes			
Walleye	(B)	All species	(B)		
b/Black basses	(N)	Black basses	(B,N)	Black basses	(B)
b/Largemouth bass	(N)	Largemouth bass	(B,N)	Largemouth bass	(B)
b/White crappie	(B)	Spotted bass	(B,N)	Spotted bass	(B,N)
b/Warmouth	(N)	Crappies	(B)	Crappies	(B)
c/Temperate bass	(N)	Black crappie	(B,N)	Black crappie	(B,N)
b/White bass	(B)	Threadfin shad	(B)	Green sunfish	(N)
		Gizzard shad	(N)	Gizzard shad	(N)
		Intermediate-Size Fish			
b/Spotted bass	(N)	All species	(B)		
c/White bass	(N)	Sport fishes	(B)	Sport fishes	(B)
		Spotted bass	(N)	Black basses	(N)
		Lepomid sunfish	(B,N)	Largemouth bass	(N)
		Bluegill	(B,N)	Green sunfish	(B,N)
		Green sunfish	(N)	Temperate basses	(N)
		White bass	(N)	White bass	(B,N)
		Threadfin shad	(B,N)	Common carp	(N)
				Redhorses	(N)
				Threadfin shad	(B,N)
		All Size Fish			
		All species	(B,N)	Sport fishes	(B)
		Sport fishes	(B)		
		Minnows	(B)		

NOTE: The few correlates that had inverse relations to those shown here are discussed in the text.

a/ Unit of variable (noted in parentheses) is B (biomass) or N (number).

b/ Significant at $\alpha = 0.10$.

c/ Significant at $\alpha = 0.20$.

Table 6

Fish Variables That Were Correlated at $\alpha = 0.05$ (Unless Indicated Otherwise) with Fall Area (Previous Year), Winter-Spring or Spring Area, or with Summer Area in Hydropower Mainstream Reservoirs[a/]

Fall Area (Previous Year) Positive Correlates		Winter-Spring or Spring Area Positive Correlates		Spring Storage Ratio Negative Correlates	
Small Fishes					
Warmouth	(B,N)	White crappie	(B)	Largemouth bass	(B)
b/Crappies	(N)	Warmouth	(N)	White crappie	(B,N)
c/Lepomid sunfish	(B)	Temperate basses	(B)	Freshwater drum	(B,N)
		White bass	(B)	b/Sport fishes	(N)
		b/Freshwater drum	(B)	b/Black basses	(B,N)
		c/All species	(B)	b/Pikes	(N)
		c/Lepomid sunfishes	(B)	b/Warmouth	(N)
				b/Lepomid sunfishes	(N)
Intermediate-Size Fishes					
Largemouth bass	(B)	Black basses	(B,N)	Largemouth bass	(N)
Spotted bass	(N)	Largemouth bass	(B,N)	Common carp	(B)
Crappies	(B,N)	c/Spotted bass	(N)	b/Black basses	(N)
White crappie	(B,N)	c/White bass	(N)	b/Crappies	(N)
Warmouth	(B)	c/Pikes	(B)	b/White crappie	(N)
Gizzard shad	(N)	c/Redear sunfish	(B)	b/Sauger	(N)
c/Black basses	(B)	c/Freshwater drum	(B,N)	b/Gizzard Shad	(N)
c/Lepomid sunfish	(B,N)				
All Size Fishes					
b/All species	(B)	Golden shiner	(B)	Golden shiner	(B)
		Minnows	(B)	b/Minnows	(B)
				b/Sport fishes	(N)

NOTE: The few correlates that had inverse relations to those shown here are discussed in the text.

a/ Unit of variable (noted in parentheses) is B (biomass) or N (number).

b/ Correlated at $\alpha = 0.10$.

c/ Correlated at $\alpha = 0.20$.

Table 7

Fish Variables That Were Correlated at $\alpha = 0.05$ (Unless Indicated Otherwise) with Area in Fall, Winter-Spring or Spring, and in Summer in Flood Control Reservoirs[a/]

Fall Area (Previous Year)		Winter-Spring or Spring Area		Summer Area	
Positive Correlates	Negative Correlates	Positive Correlates	Negative Correlates	Positive Correlates	Negative Correlates
Small Fishes					
Spotted bass (B)	White crappie (B,N)	Sport fishes (B,N)	Catfishes (B,N)	Sport fishes (B)	Catfishes (B,N)
Bluegills (B,N)	Black crappie (B,N)	Bluegills (B)	Channel catfish (B,N)	b/All species (B)	Channel catfish (B,N)
Lepomid sunfishes (B,N)	Catfishes (N)	Lepomid sunfishes (B)	Buffalo fishes (N)	c/Crappies (B,N)	
	Channel catfish (N)	b/Temperate basses (B)	Freshwater drum (B)	c/Lepomid sunfishes (B)	
		c/Green sunfish (B)			
Intermediate-Size Fishes					
Largemouth bass (B)	Catfishes (N)	Crappies (B)			
Black crappie (B)	Channel catfish (N)	White crappie (B)	All species (B,N)	Sport fishes (N)	c/Gizzard shad (N)
Redear sunfish (B)		Warmouth (N)	Gizzard shad (B)	Black basses (N)	
Lepomid sunfishes (B,N)		c/Green sunfish (B,N)	Common carp (B,N)	Largemouth bass (N)	
			Smallmouth buffalo (N)	Warmouth (N)	
			c/Carpsuckers (B,N)	c/Temperate basses (B,N)	
				c/White bass (B,N)	
				c/Lepomid sunfish (N)	
All Size Fishes					
		c/Sport fishes (N)	c/All species (N)	All species (B)	Minnows (B,N)
			b/Minnows (B)	Sport fishes (B,N)	

a/ Unit of variable (noted in parentheses) is B (biomass) or N (number).
b/ Correlated at $\alpha = 0.10$.
c/ Correlated at $\alpha = 0.20$.

APPENDIX A: REGRESSION EQUATIONS RELATING FISH BIOMASS OR DENSITY TO SELECT HYDROLOGIC VARIABLES IN HYDROPOWER STORAGE RESERVOIRS

Definitions of Terms or Symbols Used in Appendix A

Independent variables in the regression equations were defined in Table 2. Other abbreviations or definitions are as follows:

Biomass	Standard normal deviation in fish biomass (kilograms/hectare) in August.
Density	Standard normal deviation in fish density (numbers/hectare) in August.
F	A common statistic used to test for significance; F = explained variation/unexplained variation.
N	Sample size.
P > F	The significance probability of F is the probability of obtaining an F this large or larger by chance, when the hypothesis on no correlation is true.
TL	Total length in mm.

APPENDIX A

Regression Equations Relating Fish Biomass or Density to Select Hydrologic Variables in Hydropower Storage Reservoirs

Reservoir fishes (all species and small, intermediate, and large sizes)

biomass = $0.059 + 0.558\,(dA\ 3 - 5)$

$N = 25 \quad F = 11.1 \quad P > F = 0.0029 \quad r^2 = 0.33$

biomass = $0.015 - 0.974\,(WSA) + 1.143\,(SPA) + 0.577\,(dA\ 3 - 5) + 0.412\,(dA\ 6 - 8)$

$N = 25 \quad F = 5.2 \quad P > F = 0.0047 \quad R^2 = 0.51$

density = $0.012 + 0.583\,(dA/yr)$

$N = 25 \quad F = 8.7 \quad P > F = 0.0071 \quad r^2 = 0.28$

Small reservoir fishes ($\leq$ 114 mm TL)

biomass = $0.053 + 0.507\,(dA\ 3 - 5)$

$N = 25 \quad F = 8.5 \quad P > F = 0.0079 \quad r^2 = 0.27$

biomass = $-0.080 + 0.596\,(SPSR) + 0.924\,(SPA) - 0.746\,(FSR) - 0.339\,(FA)$

$N = 25 \quad F = 9.0 \quad P > F = 0.0002 \quad R^2 = 0.64$

Sport fishes (all species and small, intermediate, and large sizes)

biomass = $0.062 + 0.593\,(dA\ 3 - 5)$

$N = 25 \quad F = 13.4 \quad P > F = 0.0013 \quad r^2 = 0.37$

biomass = $-0.001 + 0.423\,(SPA) + 0.484\,(dA\ 3 - 5)$

$N = 25 \quad F = 12.6 \quad P > F = 0.0002 \quad R^2 = 0.54$

density = $-0.041 + 0.383\,(SUA)$

$N = 25 \quad F = 4.4 \quad P > F = 0.0472 \quad r^2 = 0.16$

Small sport fishes ($\leq$ 114 mm TL)

biomass = $-0.064 + 0.519\,(SPA)$

$N = 25 \quad F = 8.5 \quad P > F = 0.0079 \quad r^2 = 0.27$

biomass = $-0.054 + 0.392\,(SPSR) + 0.824\,(SPA) - 0.607\,(FSR)$

$N = 25 \quad F = 6.8 \quad P > F = 0.0022 \quad R^2 = 0.49$

APPENDIX A (Continued)

Intermediate sport fishes ($114 < \text{mm TL} \leq 318$)

biomass = $0.063 - 0.590$ (dA 6 - 8)

$N = 25 \quad F = 16.2 \quad P > F = 0.0005 \quad r^2 = 0.41$

biomass = $0.021 + 0.304$ (SUA) $- 0.502$ (dA 6 - 8)

$N = 25 \quad F = 11.2 \quad P > F = 0.0004 \quad R^2 = 0.51$

Small black basses (≤ 114 mm TL)

biomass = $-0.075 + 0.610$ (SPA)

$N = 25 \quad F = 13.6 \quad P > F = 0.0012 \quad r^2 = 0.37$

biomass = $-0.078 + 0.431$ (SPSR) $+ 0.942$ (SPA) $- 0.402$ (FSR)

$N = 25 \quad F = 7.7 \quad P > F = 0.0012 \quad R^2 = 0.52$

density = $0.020 - 0.363$ (FA) $+ 0.484$ (dA 3 - 5)

$N = 25 \quad F = 6.1 \quad P > F = 0.0077 \quad R^2 = 0.36$

Intermediate black basses ($114 < \text{mm TL} \leq 318$)

biomass = $-0.069 + 0.560$ (SPA)

$N = 25 \quad F = 10.5 \quad P > F = 0.0036 \quad r^2 = 0.31$

density = $0.060 - 0.564$ (dA 6 - 8)

$N = 25 \quad F = 13.9 \quad P > F = 0.0011 \quad r^2 = 0.38$

density = $0.049 + 0.431$ (dA/yr) $- 0.375$ (dA 6 - 8)

$N = 25 \quad F = 10.4 \quad P > F = 0.0007 \quad R^2 = 0.49$

Small largemouth bass (≤ 114 mm)

biomass = $-0.076 + 0.614$ (SPA)

$N = 25 \quad F = 13.9 \quad P > F = 0.0011 \quad r^2 = 0.38$

biomass = $-0.041 + 0.377$ (SPSR) $+ 0.900$ (SPA) $- 0.498$ (FSR) $+ 0.573$ (dA 8 - 10)

$N = 25 \quad F = 7.8 \quad P > F = 0.0006 \quad R^2 = 0.61$

Small largemouth bass (continued)

density = $0.055 + 0.521\ (dA\ 3 - 5)$

$N = 25 \quad F = 9.1 \quad P > F = 0.0061 \quad r^2 = 0.28$

density = $-0.010 + 0.544\ (SUA) - 0.673\ (FSR) - 0.370\ (FA) + 0.558\ (dA\ 8 - 10)$

$N = 25 \quad F = 8.8 \quad P > F = 0.0003 \quad R^2 = 0.64$

Intermediate largemouth bass ($114 < $ mm TL ≤ 318)

biomass = $-0.071 + 0.574\ (SPA)$

$N = 25 \quad F = 11.3 \quad P > F = 0.0027 \quad r^2 = 0.33$

density = $0.060 - 0.559\ (dA\ 6 - 8)$

$N = 25 \quad F = 13.6 \quad P > F = 0.0012 \quad r^2 = 0.37$

density = $-0.023 - 0.426\ (FA) + 0.630\ (dA/yr)$

$N = 25 \quad F = 10.2 \quad P > F = 0.0007 \quad r^2 = 0.48$

density = $0.043 - 0.774\ (WSA) + 1.113\ (SPA) - 0.509\ (SUA) + 0.698\ (dA/yr)$

$N = 25 \quad F = 8.5 \quad P > F = 0.0004 \quad R^2 = 0.63$

Small spotted bass (≤ 114)

biomass = $-0.059 + 0.726\ (dA\ 3 - 5)$

$N = 10 \quad F = 12.5 \quad P > F = 0.0077 \quad r^2 = 0.61$

biomass = $-0.116 - 0.492\ (FA) + 0.730\ (dA\ 3 - 5) - 0.602\ (dA\ 8 - 10)$

$N = 10 \quad F = 11.9 \quad P > F = 0.0061 \quad R^2 = 0.86$

density = $0.088 - 0.720\ (FA)$

$N = 10 \quad F = 6.3 \quad P > F = 0.0364 \quad r^2 = 0.44$

density = $0.059 + 0.599\ (SPA) - 0.757\ (FA)$

$N = 10 \quad F = 23.5 \quad P > F = 0.0008 \quad R^2 = 0.87$

Intermediate spotted bass ($114 < $ mm TL ≤ 318)

density = $0.185 - 0.525\ (SPSR) + 0.845\ (dA\ 8 - 10)$

$N = 10 \quad F = 6.4 \quad P > F = 0.0181 \quad R^2 = 0.68$

APPENDIX A (Continued)

Small smallmouth bass (≤ 114 mm)

biomass = $-0.143 - 1.785\ (dA/yr) + 1.542\ (dA\ 3 - 5) - 0.644\ (dA\ 8 - 10)$

$N = 10 \quad F = 12.9 \quad P > F = 0.0050 \quad R^2 = 0.87$

density = $-0.036 + 1.985\ (SUA) - 2.360\ (dA/yr)$

$N = 10 \quad F = 8.7 \quad P > F = 0.0127 \quad R^2 = 0.71$

density = $0.146 + 1.172\ (WSA) + 0.703\ (FSR) - 2.389\ (dA/yr) + 1.340\ (dA\ 3 - 5)$

$N = 10 \quad F = 22.0 \quad P > F = 0.0023 \quad R^2 = 0.95$

Intermediate smallmouth bass ($114 <$ mm TL ≤ 318)

density = $0.043 - 0.750\ (WSA)$

$N = 10 \quad F = 16.2 \quad P > F = 0.0038 \quad r^2 = 0.67$

density = $-0.191 - 1.576\ (WSA) - 0.936\ (FSR) + 0.756\ (dA/yr)$

$N = 10 \quad F = 27.4 \quad P > F = 0.0007 \quad R^2 = 0.93$

Small crappies (≤ 89 mm TL)

biomass = $-0.099 + 0.544\ (SPA)$

$N = 24 \quad F = 8.6 \quad P > F = 0.0078 \quad r^2 = 0.28$

biomass = $-0.118 + 0.450\ (SPA) - 0.593\ (FA) + 0.276\ (dA\ 3 - 5)$

$N = 24 \quad F = 10.8 \quad P > F = 0.0002 \quad R^2 = 0.62$

density = $-0.074 - 0.664\ (FA)$

$N = 24 \quad F = 9.3 \quad P > F = 0.0059 \quad r^2 = 0.30$

density = $-0.154 + 0.447\ (SPA) - 0.653\ (FA)$

$N = 24 \quad F = 9.9 \quad P > F = 0.0009 \quad R^2 = 0.49$

Small and intermediate white crappie (≤ 89 mm TL and $89 <$ mm TL ≤ 140) - NO SIGNIFICANT RELATIONS

Small black crappie (≤ 89 mm TL)

biomass = $-0.099 - 0.748\ (FA)$

$N = 19 \quad F = 9.0 \quad P > F = 0.0081 \quad r^2 = 0.35$

Small black crappie (continued)

biomass = $-0.255 + 0.499\ (SPA) - 0.675\ (FA)$

$N = 19 \quad F = 10.2 \quad P > F = 0.0014 \quad R^2 = 0.56$

density = $-0.212 + 0.463\ (WSA) - 0.706\ (FA) + 0.339\ (dA\ 3 - 5)$

$N = 19 \quad F = 9.8 \quad P > F = 0.0008 \quad R^2 = 0.66$

Small lepomid sunfishes (≤ 89 mm TL)

density = $0.018 + 0.431\ (SPSR)$

$N = 25 \quad F = 6.4 \quad P > F = 0.0188 \quad r^2 = 0.22$

density = $-0.020 + 0.543\ (SPSR) + 0.460\ (dA/yr) + 0.483\ (dA\ 6 - 8)$

$N = 25 \quad F = 5.1 \quad P > F = 0.0084 \quad R^2 = 0.42$

Intermediate lepomid sunfishes ($89 <$ mm TL ≤ 140)

biomass = $-0.086 + 0.695\ (SPA)$

$N = 25 \quad F = 21.5 \quad P > F = 0.0001 \quad r^2 = 0.48$

biomass = $-0.075 + 0.742\ (SPA) + 0.551\ (dA\ 3\text{-}5)$

$N = 25 \quad F = 14.8 \quad P > F = 0.0001 \quad R^2 = 0.68$

Small bluegills (≤ 89 mm TL) - NO SIGNIFICANT RELATIONS

Intermediate bluegills ($89 <$ mm TL ≤ 140)

biomass = $-0.086 + 0.694\ (SPA)$

$N = 25 \quad F = 21.4 \quad P > F = 0.0001 \quad r^2 = 0.48$

biomass = $-0.034 + 0.593\ (SPA) + 0.377\ (dA\ 3 - 5)$

$N = 25 \quad F = 21.4 \quad P > F = 0.0001 \quad R^2 = 0.62$

density = $0.064 + 0.606\ (dA\ 3 - 5)$

$N = 25 \quad F = 14.4 \quad P > F = 0.0010 \quad r^2 = 0.39$

density = $0.044 - 0.443\ (SPSR) + 0.590\ (dA\ 3 - 5)$

$N = 25 \quad F = 17.5 \quad P > F = 0.0001 \quad R^2 = 0.62$

APPENDIX A (Continued)

Small warmouth ($\leq$ 89 mm TL) - NO SIGNIFICANT RELATIONS

Intermediate warmouth (89 $<$ mm TL $\leq$ 140)

biomass = $-0.074 + 0.460$ (WSA)

N = 24 F = 5.4 $P > F = 0.0295$ $r^2 = 0.20$

Small green sunfish ($\leq$ 89 mm TL)

biomass = $0.029 - 0.562$ (FSR)

N = 25 F = 4.8 $P > F = 0.0393$ $r^2 = 0.17$

density = $0.006 - 0.373$ (FSR) $+ 0.528$ (dA 3 - 5) $+ 0.641$ (dA 6 - 8)

N = 25 F = 4.8 $P > F = 0.0040$ $R^2 = 0.46$

Large green sunfish ($\leq$ 89 mm TL)

biomass = $-0.076 + 0.619$ (SPA)

N = 25 F = 14.3 $P > F = 0.0010$ $r^2 = 0.38$

biomass = $-0.105 + 0.597$ (SPA) $- 0.377$ (FA)

N = 25 F = 10.00 $P > F = 0.0008$ $R^2 = 0.48$

density = $0.014 + 0.683$ (dA/yr)

N = 25 F = 13.9 $P > F = 0.0011$ $r^2 = 0.38$

Small temperate basses ($\leq$ 114 mm TL) - NO SIGNIFICANT RELATIONS

Intermediate temperate basses (114 $<$ mm TL $\leq$ 318)

density = $-0.022 + 0.521$ (dA/yr)

N = 20 F = 6.3 $P > F = 0.0220$ $r^2 = 0.26$

density = $-0.071 + 0.322$ (WSA) $- 0.391$ (dA 6 - 8)

N = 20 F = 4.5 $P > F = 0.0279$ $R^2 = 0.34$

Small white bass ($\leq$ 114 mm TL) - NO SIGNIFICANT RELATIONS

APPENDIX A (Continued)

Intermediate white bass (114 $<$ mm TL $\leq$ 318)

density = 0.068 - 0.610 (dA 6 - 8)

N = 15 F = 12.8 $P > F$ = 0.0034 r^2 = 0.50

density = -0.014 + 0.807 (SPA) - 0.517 (SUA) - 0.552 (dA 6 - 8)

N = 15 F = 13.5 $P > F$ = 0.0005 R^2 = 0.79

Small yellow perch ($\leq$ 89 mm TL)

density = -0.067 + 0.563 (SUA)

N = 15 F = 6.4 P F = 0.0248 r^2 = 0.33

density = -0.050 + 0.295 (SPSR) + 0.654 (SUA)

N = 15 F = 4.4 P F = 0.0376 R^2 = 0.42

Small walleye ($\leq$ 140 mm TL)

biomass = -0.237 + 1.304 (dA 8 - 10)

N = 5 F = 13.4 $P > F$ = 0.0352 r^2 = 0.82

Small and intermediate pikes ($\leq$ 190.5 mm TL and 190.5 $<$ mm TL $\leq$ 381) - NO SIGNIFICANT RELATIONS

Small catfishes ($\leq$ 114 mm TL)

biomass = -0.053 - 0.634 (FA)

N = 25 F = 8.4 $P >$ F 0.0083 r^2 = 0.27

biomass = -0.150 + 0.555 (WSA) - 0.738 (FA) - 0.423 (dA/yr)

N = 25 F = 4.7 $P > F$ = 0.0118 R^2 = 0.40

Small channel catfish ($\leq$ 114 mm TL)

biomass = -0.[illegible]5 - 0.639 (FA)

N = 22 F = 8.2 $P > F$ = 0.0096 r^2 = 0.30

biomass = -0.067 + 0.466 (WSA) - 0.630 (FA) - 0.606 (dA/yr) - 0.312 (dA 5 - 8)

N = 22 F = 3.4 $P > F$ = 0.0333 R^2 = 0.44

APPENDIX A (Continued)

Small flathead catfish ($\leq$ 114 mm TL)

biomass = $0.086 - 0.703\ (FA)$

N = 10 F = 5.8 $P > F = 0.043$ $r^2 = 0.42$

biomass = $0.062 + 1.148\ (SPA) - 0.664\ (FA) - 0.774\ (dA/yr)$

N = 10 F = 10.0 $P > F = 0.0096$ $R^2 = 0.83$

density = $0.093 + 1.086\ (SPA) - 1.168\ (FA) + 1.049\ (dA\ 6 - 8)$

N = 10 F = 24.2 $P > F = 0.0009$ $R^2 = 0.92$

Intermediate flathead catfish (114 < mm TL $\leq$ 318)

density = $-0.016 + 1.198\ (FA) - 0.565\ (dA\ 6 - 8) + 0.700\ (dA\ 8 - 10)$

N = 10 F = 12.5 $P > F = 0.0055$ $R^2 = 0.86$

Intermediate common carp (114 < mm TL $\leq$ 318)

density = $-0.104 + 0.590\ (dA/yr)$

N = 13 F = 10.5 $P > F = 0.0080$ $r^2 = 0.49$

density = $-0.050 + 0.575\ (dA/yr) + 0.294\ (dA\ 8 - 10)$

N = 13 F = 6.6 $P > F = 0.0147$ $R^2 = 0.57$

Intermediate redhorses (89 < mm TL $\leq$ 318)

biomass = $-0.025 + 0.600\ (SPA)$

N = 17 F = 12.8 $P > F = 0.0027$ $r^2 = 0.46$

biomass = $0.010 + 0.887\ (SPA) - 0.368\ (FA) + 0.442\ (dA\ 6 - 8)$

N = 17 F = 6.14 $P > F = 0.0079$ $R^2 = 0.59$

density = $-0.027 + 0.630\ (SPA)$

N = 17 F = 15.4 $P > F = 0.0013$ $r^2 = 0.51$

density = $0.007 + 0.614\ (SPA) - 0.401\ (FA)$

N = 17 F = 12.3 $P > F = 0.0008$ $R^2 = 0.64$

APPENDIX A (Continued)

Intermediate golden redhorse (89 $<$ mm TL $\leq$ 318)

density = $-0.044 + 0.523\ (SPA) - 0.930\ (FA) - 0.660\ (dA\ 8 - 10)$

$N = 10 \quad F = 15.0 \quad P > F = 0.0034 \quad R^2 = 0.88$

Small threadfin shad ($\leq$ 89 mm TL)

biomass = $0.108 + 0.601\ (dA\ 3 - 5)$

$N = 19 \quad F = 7.7 \quad P > F = 0.0129 \quad r^2 = 0.31$

biomass = $-0.192 + 0.504\ (SPSR) + 0.819\ (SUA) - 0.820\ (FSR)$

$N = 19 \quad F = 6.3 \quad P > F = 0.0056 \quad R^2 = 0.56$

Large threadfin shad ($\leq$ 89 mm TL)

biomass = $-0.102 + 0.863\ (SPA)$

$N = 16 \quad F = 25.8 \quad P > F = 0.0002 \quad r^2 = 0.65$

biomass = $0.115 - 2.178\ (WSA) + 3.113\ (SPA) + 0.672\ (dA\ 6 - 8)$

$N = 16 \quad F = 38.4 \quad P > F = 0.0001 \quad R^2 = 0.91$

Small gizzard shad ($\leq$114 mm TL)

density = $0.047 - 0.495\ (dA\ 6 - 8)$

$N = 21 \quad F = 9.6 \quad P > F = 0.0058 \quad r^2 = 0.34$

density = $0.019 - 0.355\ (FSR) - 0.445\ (FA) - 0.458\ (dA\ 6 - 8)$

$N = 21 \quad F = 6.2 \quad P > F = 0.0048 \quad R^2 = 0.52$

Golden shiners (all sizes)

density = $0.406 + 0.707\ (WSA) + 0.564\ (SPSR) + 1.345\ (dA\ 3 - 5) - 1.767\ (dA\ 8 - 10)$

$N = 11 \quad F = 5.6 \quad P > F = 0.0315 \quad R^2 = 0.79$

Minnows (all sizes)

biomass = $-0.082 + 0.286\ (SPSR) + 0.551\ (SUA) - 0.410\ (FA)$

$N = 25 \quad F = 3.9 \quad P > F = 0.0249 \quad R^2 = 0.35$

APPENDIX A (Concluded)

Minnows (all sizes) (continued)

density = $-0.049 + 0.451$ (SUA)

$N = 25 \quad F = 6.6 \quad P > F = 0.0174 \quad r^2 = 0.22$

density = $-0.022 - 0.464$ (SPA) $+ 0.731$ (SUA)

$N = 25 \quad F = 6.0 \quad P > F = 0.0085 \quad R^2 = 0.35$

APPENDIX B: REGRESSION EQUATIONS RELATING FISH BIOMASS OR DENSITY TO SELECT HYDROLOGIC VARIABLES IN HYDROPOWER MAINSTREAM RESERVOIRS

Definitions of Terms or Symbols Used in Appendix B

Independent variables in the regression equations were defined in Table 2. Other abbreviations or definitions are as follows:

Biomass	Standard normal deviation in fish biomass (kilograms/hectare) in August.
Density	Standard normal deviation in fish density (numbers/hectare) in August.
F	A common statistic used to test for significance; F = explained variation/unexplained variation.
N	Sample size.
P > F	The significance probability of F is the probability of obtaining an F this large or larger by chance, when the hypothesis on no correlation is true.
TL	Total length in mm.

APPENDIX B

Regression Equations Relating Fish Biomass or Density to Select Hydrologic Variables in Hydropower Mainstream Reservoirs

Reservoir fishes (all species and small, intermediate, and large sizes)

density = $-0.031 + 0.532\ (WSA) - 0.688\ (SUA) - 0.318\ (FSR) + 0.560\ (dA/yr)$

$N = 17 \quad F = 4.9 \quad P > F = 0.0141 \quad R^2 = 0.62$

Small reservoir fishes (≤ 114 mm TL)

biomass = $0.0019 + 0.838\ (SPA) - 0.914\ (SUA) - 0.297\ (FSR)$

$N = 17 \quad F = 8.9 \quad P > F = 0.0018 \quad R^2 = 0.67$

density = $-0.042 + 0.414\ (WSA) - 0.696\ (SUA) + 0.617\ (dA/yr)$

$N = 17 \quad F = 5.2 \quad P > F = 0.0142 \quad R^2 = 0.54$

Intermediate reservoir fishes ($114 <$ mm TL ≤ 318)

density = $-0.092 + 0.533\ (FA)$

$N = 17 \quad F = 8.9 \quad P > F = 0.0092 \quad r^2 = 0.37$

density = $-0.007 + 0.382\ (WSA) + 0.569\ (FA)$

$N = 17 \quad F = 9.0 \quad P > F = 0.0031 \quad R^2 = 0.56$

Sport fishes (all species and small, intermediate, and large sizes)

density = $-0.110 + 0.570\ (dA/yr)$

$N = 17 \quad F = 6.7 \quad P > F = 0.0204 \quad r^2 = 0.31$

density = $-0.042 + 0.287\ (WSA) + 0.577\ (dA/yr)$

$N = 17 \quad F = 5.0 \quad P > F = 0.0228 \quad R^2 = 0.42$

Small sport fishes (≤ 114 mm TL)

density = $-0.119 + 0.616\ (dA/yr)$

$N = 17 \quad F = 8.5 \quad P > F = 0.0106 \quad r^2 = 0.36$

density = $-0.119 - 0.243\ (SPSR) + 0.703\ (dA/yr) - 0.274\ (dA8\text{-}10)$

$N = 17 \quad F = 4.8 \quad P > F = 0.0178 \quad R^2 = 0.53$

APPENDIX B (Continued)

Small black basses ($\leq$ 114 mm TL)

biomass = $-0.269 + 0.545\ (FA) + 0.615\ (dA/yr) + 0.286\ (dA3\text{-}5) - 0.939\ (dA8\text{-}10)$

$N = 17 \quad F = 5.7 \quad P > F = 0.0085 \quad R^2 = 0.65$

density = $-0.106 + 0.551\ (dA/yr)$

$N = 17 \quad F = 6.1 \quad P > F = 0.0259 \quad r^2 = 0.29$

Intermediate black basses (114 $<$ mm TL $\leq$ 318)

biomass = $0.034 + 0.499\ (SPA)$

$N = 17 \quad F = 8.1 \quad P > F = 0.0123 \quad r^2 = 0.35$

biomass = $-0.030 + 0.487\ (SPA) + 0.368\ (FA)$

$N = 17 \quad F = 7.8 \quad P > F = 0.0052 \quad R^2 = 0.53$

density = $-0.107 + 0.521\ (WSA) + 0.311\ (SPSR) + 1.110\ (FA) - 0.906\ (dA8\text{-}10)$

$N = 17 \quad F = 7.0 \quad P > F = 0.0038$

Small largemouth bass ($\leq$ 114 mm TL)

biomass = $0.088 - 0.483\ (SPSR)$

$N = 16 \quad F = 5.8 \quad P > F = 0.0307 \quad r^2 = 0.29$

biomass = $0.009 - 0.464\ (SPSR) + 0.446\ (dA3\text{-}5) - 0.228\ (dA8\text{-}10)$

$N = 16 \quad F = 5.9 \quad P > F = 0.0102 \quad R^2 = 0.60$

density = $-0.068 + 0.466\ (dA3\text{-}5)$

$N = 16 \quad F = 5.8 \quad P > F = 0.0300 \quad r^2 = 0.29$

Intermediate largemouth bass (114 $<$ mm TL $\leq$ 318)

biomass = $0.049 + 0.506\ (SPA)$

$N = 16 \quad F = 8.8 \quad P > F = 0.0103 \quad r^2 = 0.38$

biomass = $0.103 + 0.573\ (WSA) + 0.501\ (FA)$

$N = 16 \quad F = 14.1 \quad P > F = 0.0006 \quad R^2 = 0.68$

Small spotted bass ($\leq$ 114 mm TL) - NO SIGNIFICANT RELATIONS

APPENDIX B (Continued)

Intermediate spotted bass ($114 < \text{mm TL} \leq 318$)

biomass = $-1.620 - 4.052$ (FSR) $- 0.489$ (dA8-10)

$N = 8 \quad F = 12.8 \quad P > F = 0.0122 \quad R^2 = 0.83$

density = $-0.131 - 0.574$ (dA8-10)

$N = 8 \quad F = 12.6 \quad P > F = 0.0120 \quad r^2 = 0.68$

Smallmouth bass - SAMPLE SIZE WAS INSUFFICIENT

Small white crappie (≤ 89 mm TL)

biomass = $0.138 + 0.761$ (WSA)

$N = 11 \quad F = 23.9 \quad P > F = 0.0009 \quad R^2 = 0.73$

biomass = $0.116 + 0.593$ (WSA) $- 0.283$ (SPSR)

$N = 11 \quad F = 15.4 \quad P > F = 0.0018 \quad R^2 = 0.79$

Intermediate white crappie ($89 < \text{mm TL} \leq 140$)

biomass = $-0.047 + 0.582$ (FA)

$N = 11 \quad F = 7.7 \quad P > F = 0.0215 \quad r^2 = 0.46$

biomass = $-0.110 + 0.999$ (FA) $- 0.494$ (dA8-10)

$N = 11 \quad F = 6.1 \quad P > F = 0.0251 \quad R^2 = 0.60$

Small black crappie (≤ 89 mm TL)

biomass = $-0.046 + 0.595$ (dA3-5)

$N = 12 \quad F = 10.7 \quad P > F = 0.0085 \quad r^2 = 0.52$

biomass = $-0.041 - 0.261$ (SPSR) $+ 0.812$ (dA3-5) $+ 0.513$ (dA6-8)

$N = 12 \quad F = 8.9 \quad P > F = 0.0063 \quad R^2 = 0.77$

Intermediate black crappie ($89 < \text{mm TL} \leq 318$) - NO SIGNIFICANT RELATIONS

APPENDIX B (Continued)

Small lepomid sunfishes ($\leq$ 89 mm TL)

density = $-0.122 + 0.631$ (dA/yr)

$N = 17$ $F = 9.2$ $P > F = 0.0084$ $r^2 = 0.38$

biomass = $-0.082 - 0.287$ (SPSR) + 0.554 (dA/yr)

$N = 17$ $F = 9.2$ $P > F = 0.0084$ $R^2 = 0.38$

Intermediate lepomid sunfishes (89 < mm TL $\leq$ 140) - NO SIGNIFICANT RELATIONS

Small bluegills ($\leq$ 89 mm TL)

density = $-0.115 + 0.594$ (dA/yr)

$N = 17$ $F = 7.6$ $P > F = 0.0147$ $r^2 = 0.34$

density = $-0.275 + 0.597$ (FA) + 0.819 (dA/yr) - 0.910 (dA8-10)

$N = 17$ $F = 8.3$ $P > F = 0.0027$ $R^2 = 0.66$

Intermediate bluegills (89 < mm TL $\leq$ 140) - NO SIGNIFICANT RELATIONS

Small green sunfishes

biomass = $0.091 - 0.857$ (dA/yr) + 0.534 (dA8-10)

$N = 11$ $F = 5.0$ $P > F = 0.0397$ $R^2 = 0.55$

Small warmouth ($\leq$ 89 mm TL)

biomass = $-0.025 + 0.532$ (dA8-10)

$N = 16$ $F = 8.1$ $P > F = 0.0128$ $r^2 = 0.37$

density = $0.109 + 0.479$ (WSA)

$N = 16$ $F = 6.7$ $P > F = 0.0219$ $r^2 = 0.32$

density = $0.035 + 0.484$ (WSA) + 0.484 (dA/yr)

$N = 16$ $F = 8.1$ $P > F = 0.0052$ $R^2 = 0.56$

APPENDIX B (Continued)

Intermediate warmouth ($89 < \text{mm TL} \leq 140$)

biomass = $-0.113 + 0.734$ (dA/yr)

$N = 16$ $F = 16.2$ $P > F = 0.0013$ $r^2 = 0.54$

biomass = $-0.098 + 0.635$ (dA/yr) $- 0.325$ (dA3-5) $+ 0.343$ (dA8-10)

$N = 16$ $F = 11.0$ $P > F = 0.0009$ $R^2 = 0.734$

Small redear sunfish (≤ 89 mm TL)

biomass = $0.010 + 0.519$ (dA6-8)

$N = 10$ $F = 6.9$ $P > F = 0.0302$ $r^2 = 0.46$

biomass = $-0.069 + 0.559$ (FSR) $+ 0.889$ (dA6-8) $+ 0.361$ (dA8-10)

$N = 10$ $F = 15.8$ $P > F = 0.0030$ $R^2 = 0.89$

Intermediate redear sunfish ($89 < \text{mm TL} \leq 140$)

density = $0.179 + 0.598$ (SUA) $- 0.949$ (dA/yr) $+ 0.672$ (dA8-10)

$N = 13$ $F = 6.9$ $P > F = 0.0105$ $R^2 = 0.70$

Small temperate basses (≤ 114 mm TL)

biomass = $-0.031 + 0.534$ (SPA)

$N = 8$ $F = 8.1$ $P > F = 0.0291$ $r^2 = 0.58$

Intermediate temperate basses ($114 < \text{mm TL} \leq 318$)

biomass = $0.077 + 0.831$ (SPSR) $+ 0.716$ (SUA)

$N = 12$ $F = 8.8$ $P > F = 0.0076$ $R^2 = 0.66$

density = $-0.232 + 0.479$ (SPSR) $+ 0.686$ (dA/yr)

$N = 12$ $F = 6.8$ $P > F = 0.0159$ $R^2 = 0.60$

Small white bass (≤ 114 mm TL)

biomass = $-0.036 + 0.623$ (SPA)

$N = 8$ $F = 21.7$ $P > F = 0.0035$ $r^2 = 0.78$

APPENDIX B (Continued)

Intermediate white bass ($114 < \text{mm TL} \leq 318$)

biomass = $-0.016 + 1.065\ (SPSR) + 1.035\ (SUA) + 0.403\ (FA)$

$N = 11 \quad F = 14.0 \quad P > F = 0.0024 \quad R^2 = 0.86$

density = $-0.052 - 0.106\ (WSA) + 1.093\ (SPA)$

$N = 11 \quad F = 17.5 \quad P > F = 0.0012 \quad R^2 = 0.81$

Small (≤ 89 mm TL) and intermediate ($89 < \text{mm TL} \leq 140$) yellow perch - NO SIGNIFICANT RELATIONS ($N = 6$)

Small sauger (>140 mm TL) - SAMPLE SIZE WAS INSUFFICIENT

Intermediate sauger ($140 < \text{mm TL} \leq 318$)

biomass = $0.040 + 0.672\ (FSR)$

$N = 10 \quad F = 24.6 \quad P > F = 0.0011 \quad r^2 = 0.75$

biomass = $0.115 + 0.663\ (FSR) - 0.415\ (FA) + 0.494\ (dA8\text{-}10)$

$N = 10 \quad F = 20.3 \quad P > F = 0.0015 \quad R^2 = 0.91$

density = $0.049 + 0.268\ (SPSR) + 0.584\ (FSR)$

$N = 10 \quad F = 18.4 \quad P > F = 0.0016 \quad R^2 = 0.84$

Small catfishes (≤ 114 mm TL)

biomass = $0.025 + 0.732\ (dA6\text{-}8)$

$N = 12 \quad F = 5.5 \quad P > F = 0.0408 \quad r^2 = 0.36$

density = $-0.065 - 0.383\ (SUA) - 0.510\ (dA8\text{-}10)$

$N = 12 \quad F = 6.9 \quad P > F = 0.0155 \quad R^2 = 0.60$

Intermediate catfishes ($114 < \text{mm TL} \leq 318$)

density = $-0.096 + 0.627\ (FSR) + 0.608\ (dA/yr) + 0.758\ (dA6\text{-}8)$

$N = 16 \quad F = 4.2 \quad P > F = 0.0303 \quad R^2 = 0.51$

Small channel catfish (114 mm TL) - NO SIGNIFICANT RELATIONS ($N = 7$)

APPENDIX B (Continued)

Intermediate channel catfish (114 $<$ mm TL $\leq$ 318)

biomass = 0.125 + 0.684 (FSR) + 0.391 (FA)

N = 14 $F = 4.1$ $P > F = 0.0474$ $R^2 = 0.43$

density = 0.195 + 0.716 (FSR)

N = 14 $F = 8.0$ $P > F = 0.0155$ $R^2 = 0.40$

Small flathead catfish ($\leq$ 114 mm TL) - SAMPLE SIZE WAS INSUFFICIENT

Intermediate flathead catfish (114 $<$ mm TL $\leq$ 318)

biomass = -0.654 + 1.277 (dA3-5)

N = 5 $F = 31.4$ $P > F = 0.0113$ $r^2 = 0.91$

Intermediate common carp (114 $<$ mm TL $\leq$ 318)

biomass = -0.064 - 0.586 (SPSR)

N = 10 $F = 5.4$ $P > F = 0.0491$ $r^2 = 0.40$

Intermediate redhorses (89 $<$ mm TL $\leq$ 318)

density = -0.050 + 0.590 (FSR)

N = 10 $F = 7.9$ $P > F = 0.0231$ $r^2 = 0.50$

density = 0.088 + 0.450 (FSR) - 0.459 (dA/yr)

N = 10 $F = 8.7$ $P > F = 0.0127$ $R^2 = 0.71$

Intermediate golden redhorse (89 $<$ mm TL $\leq$ 318)

biomass = 0.289 - 0.773 (dA/yr)

N = 9 $F = 11.3$ $P > F = 0.0119$ $r^2 = 0.62$

biomass = 0.178 + 0.349 (FSR) - 0.605 (dA/yr)

N = 9 $F = 9.4$ $P > F = 0.0141$ $R^2 = 0.76$

Small buffalofishes ($\leq$ 89 mm TL)

biomass = -0.280 - 0.586 (WSA) + 0.990 (SUA)

N = 9 $F = 6.0$ $P > F = 0.0376$ $R^2 = 0.66$

APPENDIX B (Concluded)

Small freshwater drum ($\leq$114 mm TL)

biomass = $0.161 - 0.750$ (SPSR)

$N = 8$ $F = 34.1$ $P > F = 0.0011$ $r^2 = 0.85$

biomass = $0.134 - 0.755$ (SPSR) $+ 0.169$ (dA3-5)

$N = 8$ $F = 20.9$ $P > F = 0.0037$ $R^2 = 0.89$

Small and large threadfin shad ($<$89 mm TL and $\leq$89 mm TL) - NO SIGNIFICANT RELATIONS

Small gizzard shad ($\leq$ 114 mm TL)

density = $-0.377 + 0.783$ (FA) $+ 0.589$ (dA/yr) $- 0.874$ (dA8-10)

$N = 13$ $F = 4.4$ P F $= 0.0366$ $R^2 = 0.59$

Intermediate gizzard shad (114 $<$ mm TL $\leq$ 241)

density = $-0.072 + 0.568$ (FA)

$N = 15$ $F = 12.3$ $P > F = 0.0038$ $r^2 = 0.49$

density = $0.051 + 0.322$ (WSA) $+ 0.616$ (FA)

$N = 15$ $F = 9.5$ $P > F = 0.0034$ $R^2 = 0.61$

Golden shiner (all sizes)

biomass = $0.124 + 0.568$ (WSA)

$N = 15$ $F = 12.2$ $P > F = 0.0040$ $r^2 = 0.48$

biomass = $0.074 + 0.666$ (WSA) $+ 0.282$ (FA) $+ 0.268$ (dA3-5)

$N = 15$ $F = 8.7$ $P > F = 0.0030$ $R^2 = 0.70$

Minnows (all species and sizes)

biomass = $0.122 + 0.508$ (WSA)

$N = 17$ $F = 7.6$ $P > F = 0.0145$ $r^2 = 0.34$

biomass = $0.123 + 0.665$ (WSA) $- 0.444$ (FSR) $+ 0.244$ (dA8-10)

$N = 17$ $F = 7.6$ $P > F = 0.0035$ $R^2 = 0.64$

APPENDIX C: REGRESSION EQUATIONS RELATING FISH BIOMASS OR DENSITY TO SELECT HYDROLOGIC VARIABLES IN FLOOD CONTROL RESERVOIRS

Definitions of Terms or Symbols Used in Appendix C

Independent variables in the regression equations were defined in Table 2. Other abbreviations or definitions are as follows:

Biomass	Standard normal deviation in fish biomass (kilograms/hectare) in August.
Density	Standard normal deviation in fish density (numbers/hectare) in August.
F	A common statistic used to test for significance; F = explained variation/unexplained variation.
N	Sample size.
P > F	The significance probability of F is the probability of obtaining an F this large or larger by chance, when the hypothesis on no correlation is true.
TL	Total length in mm.

APPENDIX C

Regression Equations Relating Fish Biomass or Density to Select Hydrologic Variables in Flood Control Reservoirs

Reservoir fishes (all species and small, intermediate, and large sizes)

biomass = $-0.080 + 0.400\ (SUA)$

$N = 23 \quad F = 4.9 \quad P > F = 0.0375 \quad r^2 = 0.19$

biomass = $0.283 - 0.265\ (SPSR) + 0.310\ (SUA) + 1.014\ (FSR)$

$N = 23 \quad F = 4.8 \quad P > F = 0.0117 \quad R^2 = 0.43$

density = $0.150 - 0.410\ (WSA) - 0.400\ (dA6\text{-}8)$

$N = 23 \quad F = 3.79 \quad P > F = 0.0402 \quad r^2 = 0.27$

density = $0.452 - 0.304\ (WSA) + 0.713\ (FSR) - 0.299\ (dA/yr)$

$N = 23 \quad F = 3.2 \quad P > F = 0.0379 \quad r^2 = 0.42$

Small reservoir fishes ($\leq$114 mm TL) - NO SIGNIFICANT RELATIONS

Intermediate reservoir fishes (114 $<$ mm TL $\leq$ 318)

biomass = $0.081 - 0.447\ (WSA) + 0.262\ (dA8\text{-}10)$

$N = 23 \quad F = 7.8 \quad P > F = 0.0031 \quad R^2 = 0.44$

density = $0.091 - 0.580\ (WSA)$

$N = 22 \quad F = 19.0 \quad P > F = 0.0003 \quad r^2 = 0.48$

Sport fishes (all species and small, intermediate, and large sizes)

biomass = $-0.144 + 0.722\ (SUA)$

$N = 23 \quad F = 34.6 \quad P > F = 0.0001 \quad r^2 = 0.62$

biomass = $0.096 + 0.709\ (SUA) + 0.661\ (FSR)$

$N = 23 \quad F = 28.3 \quad P > F = 0.0001 \quad R^2 = 0.73$

density = $-0.087 + 0.544\ (SUA) - 0.436\ (dA/yr)$

$N = 23 \quad F = 5.8 \quad P > F = 0.0102 \quad R^2 = 0.37$

APPENDIX C (Continued)

Small sport fishes ($\leq$ 114 mm TL)

biomass = $-0.044 + 0.420$ (SPA)

$N = 23 \quad F = 6.9 \quad P > F = 0.0155 \quad r^2 = 0.25$

biomass = $-0.085 + 0.288$ (SPA) $+ 0.274$ (SUA)

$N = 23 \quad F = 4.6 \quad P > F = 0.0235 \quad R^2 = 0.31$

density = $-0.066 + 0.609$ (SPSR) $+ 0.829$ (SPA) $+ 0.386$ (FA) $- 0.479$ (dA/yr)

$N = 23 \quad F = 4.5 \quad P > F = 0.0106 \quad R^2 = 0.50$

Intermediate sport fishes (114 < mm TL $\leq$ 318)

biomass = $0.461 + 1.006$ (FSR) $- 0.453$ (dA6-8)

$N = 23 \quad F = 5.1 \quad P > F = 0.0166 \quad R^2 = 0.34$

density = $0.234 - 0.639$ (WSA) $- 0.665$ (SPSR) $+ 0.482$ (SUA) $+ 0.781$ (FSR)

$N = 23 \quad F = 9.3 \quad P > F = 0.0003 \quad R^2 = 0.67$

Small black basses ($\leq$ 114 mm TL) - NO SIGNIFICANT RELATIONS

Intermediate black basses (114 < mm TL $\leq$ 318)

biomass = $0.018 + 0.436$ (dA8-10)

$N = 23 \quad F = 6.0 \quad P > F = 0.0236 \quad r^2 = 0.22$

biomass = $0.105 - 0.405$ (dA6-8) $+ 0.427$ (dA8-10)

$N = 23 \quad F = 5.5 \quad P > F = 0.0123 \quad R^2 = 0.36$

density = $-0.056 + 0.362$ (SUA) $+ 0.386$ (dA8-10)

$N = 23 \quad F = 6.0 \quad P > F = 0.0094 \quad R^2 = 0.37$

Small largemouth bass ($\leq$ 114 mm TL) - NO SIGNIFICANT RELATIONS

Intermediate largemouth bass (114 < mm TL $\leq$ 318)

biomass = $0.018 + 0.428$ (dA8-10)

$N = 23 \quad F = 5.7 \quad P > F = 0.0266 \quad r^2 = 0.21$

APPENDIX C (Continued)

Intermediate largemouth bass (continued)

biomass = $0.377 + 0.746\ (FSR) + 0.366\ (FA) - 0.391\ (dA/yr) - 0.629\ (dA6\text{-}8)$

$N = 23 \quad F = 3.9 \quad P > F = 0.0189 \quad R^2 = 0.46$

density = $-0.111 + 0.553\ (SUA)$

$N = 23 \quad F = 12.1 \quad P > F = 0.0023 \quad r^2 = 0.37$

density = $-0.131 - 0.634\ (SPSR) + 0.549\ (SPA) + 0.701\ (SUA)$

$N = 23 \quad F = 0.6 \quad P > F = 0.0005 \quad r^2 = 0.60$

Small spotted bass ($\leq$ 114 mm TL)

biomass = $0.916 + 2.627\ (FSR)$

$N = 13 \quad F = 24.5 \quad P > F = 0.0004 \quad r^2 = 0.69$

biomass = $0.772 - 0.224\ (SPA) + 2.153\ (FSR) + 0.243$

$N = 13 \quad F = 11.7 \quad P > F = 0.0019 \quad R^2 = 0.796$

Intermediate spotted bass (114 $<$ mm TL $\leq$ 318)

biomass = $0.276 - 0.373\ (dA6\text{-}8) + 0.624\ (dA8\text{-}10)$

$N = 15 \quad F = 4.0 \quad P > F = 0.0465 \quad R^2 = 0.40$

Small crappies ($\leq$ 89 mm TL)

biomass = $-0.044 + 0.455\ (SUA) - 0.368\ (FA)$

$N = 23 \quad F = 4.3 \quad P > F = 0.0283 \quad R^2 = 0.30$

biomass = $0.039 - 0.911\ (WSA) + 0.587\ (SPSR) + 1.507\ (SPA) - 0.178\ (dA/yr)$

$N = 23 \quad F = 5.5 \quad P > F = 0.0043 \quad R^2 = 0.55$

density = $0.040 - 0.980\ (WSA) + 0.563\ (SPSR) + 1.498\ (SPA)$

$N = 23 \quad F = 7.1 \quad P > F = 0.0022 \quad R^2 = 0.53$

Intermediate crappies (89 $<$ mm TL $\leq$ 140)

biomass = $0.010 + 0.504\ (dA/yr)$

$N = 21 \quad F = 7.4 \quad P > F = 0.0134 \quad r^2 = 0.28$

biomass = $-0.043 + 0.261\ (WSA) + 0.426\ (dA/yr)$

$N = 21 \quad F = 5.5 \quad P > F = 0.0135 \quad R^2 = 0.38$

Small white crappie ($\leq$ 89 mm TL)

biomass = $-0.016 + 0.337$ (SUA) $- 0.461$ (FA)

N = 20 F = 4.01 $P > F = 0.375$ $R^2 = 0.32$

biomass = $0.057 - 0.986$ (WSA) $+ 0.582$ (SPSR) $+ 1.511$ (SPA)

N = 20 F = 4.80 $P > F = 0.0145$ $R^2 = 0.47$

Intermediate white crappie (89 < mm TL $\leq$ 140)

biomass = $0.106 + 0.572$ (dA/yr)

N = 17 F = 8.7 $P > F = 0.0100$ $r^2 = 0.37$

density = $0.058 + 0.291$ (SUA) $+ 0.433$ (dA/yr)

N = 17 F = 4.5 $P > F = 0.3060$ $R^2 = 0.39$

Small black crappie ($\leq$ 89 mm TL)

biomass = $0.240 - 0.611$ (FA)

N = 7 F = 7.1 $P > F = 0.0450$ $r^2 = 0.59$

density = $0.451 - 0.566$ (FA) $- 0.593$ (dA6-8)

N = 7 F = 42.6 $P > F = 0.0020$ $R^2 = 0.96$

Intermediate black crappie (89 < mm TL < 140)

biomass = $-0.225 + 0.556$ (FA)

N = 9 F = 13.5 $P > F = 0.0079$ $r^2 = 0.66$

biomass = $-0.188 - 0.228$ (SPA) $+ 0.568$ (FA)

N = 9 F = 9.7 $P > F = 0.0131$ $R^2 = 0.76$

Small lepomid sunfishes ($\leq$ 89 mm TL)

biomass = $-0.083 + 0.644$ (FA)

N = 23 F = 22.4 $P > F = 0.0001$ $r^2 = 0.52$

biomass = $-0.073 + 0.565$ (FA) $- 0.314$ (dA3-5)

N = 23 F = 16.9 $P > F = 0.0001$ $R^2 = 0.62$

Small lepomid sunfishes (continued)

density = $-0.064 + 0.653\ (FA) - 0.393\ (dA/yr)$

$N = 23 \quad F = 10.0 \quad P > F = 0.0010 \quad R^2 = 0.50$

Intermediate lepomid sunfishes ($89 <$ mm TL ≤ 140)

biomass = $-0.064 + 0.500\ (FA) + 0.201\ (dA3\text{-}5)$

$N = 23 \quad F = 4.2 \quad P > F = 0.0303 \quad R^2 = 0.30$

density = $-0.063 + 0.489\ (FA)$

$N = 23 \quad F = 8.9 \quad P > F = 0.0072 \quad r^2 = 0.30$

Small bluegills (≤ 89 mm TL)

biomass = $-0.075 + 0.509\ (FA)$

$N = 22 \quad F = 10.2 \quad P > F = 0.0045 \quad r^2 = 0.34$

biomass = $0.157 + 0.393\ (WSA) + 0.803\ (FSR) + 0.365\ (FA)$

$N = 22 \quad F = 8.4 \quad P > F = 0.0011 \quad R^2 = 0.58$

Intermediate bluegills ($89 <$ mm TL ≤ 140)

biomass = $0.504 - 0.660\ (SPSR) + 1.660\ (FSR) + 0.549\ (dA3\text{-}5) - 0.357\ (dA8\text{-}10)$

$N = 22 \quad F = 6.2 \quad P > F = 0.0030 \quad R^2 = 0.59$

Small green sunfish (≤ 89 mm TL)

biomass = $0.049 + 0.389\ (SPA) - 0.462\ (dA/yr)$

$N = 11 \quad F = 5.0 \quad P > F = 0.0387 \quad R^2 = 0.56$

density = $0.048 - 0.724\ (WSA) - 0.981\ (SPSR)$

$N = 11 \quad F = 6.1 \quad P > F = 0.0244 \quad R^2 = 0.61$

Large green sunfish (≤ 89 mm TL)

density = $0.252 - 0.625\ (dA/yr)$

$N = 11 \quad F = 6.8 \quad P > F = 0.0280 \quad r^2 = 0.43$

density = $-0.306 + 0.681\ (SPA) + 0.486\ (dA8\text{-}10)$

$N = 11 \quad F = 8.2 \quad P > F = 0.0117 \quad R^2 = 0.67$

APPENDIX C (Continued)

Small warmouth ($\leq$ 89 mm TL) - NO SIGNIFICANT EQUATIONS

Intermediate warmouth (89 $<$ mm TL $\leq$ 140)

density = $-0.168 + 0.523$ (SUA)

N = 11 F = 6.4 P $>$ F = 0.0328 $r^2 = 0.41$

density = $-0.157 + 0.746$ (SUA) $- 0.632$ (dA/yr)

N = 11 F = 15.6 P $>$ F = 0.0017 $R^2 = 0.80$

Small redear sunfish ($\leq$ 89 mm TL) - NO SIGNIFICANT EQUATIONS

Intermediate redear sunfish (89 $<$ mm TL $\leq$ 140)

biomass = $-0.123 - 0.660$ (SPSR)

N = 13 F = 14.6 P $>$ F = 0.0028 $r^2 = 0.57$

density = $0.222 - 0.478$ (SPSR) $- 0.680$ (SUA) $+ 0.669$ (dA/yr)

N = 13 F = 12.4 P $>$ F = 0.0015 $R^2 = 0.81$

Small white bass ($\leq$ 114 mm TL)

biomass = $0.056 - 0.473$ (dA8-10)

N = 15 F = 5.1 P $>$ F = 0.0413 $r^2 = 0.28$

Intermediate white bass (114 $<$ mm TL $\leq$ 318)

biomass = $-0.043 + 0.508$ (SUA) $- 0.415$ (FA)

N = 16 F = 4.6 P $>$ F = 0.0305 $R^2 = 0.42$

Small walleye ($\leq$140 mm TL) - NO SIGNIFICANT EQUATIONS

Intermediate walleye (140 $<$ mm TL $\leq$ 318)

biomass = $0.238 + 0.822$ (SPSR)

N = 6 F = 17.5 P $>$ F = 0.0139 $r^2 = 0.81$

Intermediate walleye (continued)

biomass = $0.243 + 1.380\ (SPSR) - 0.775\ (dA6\text{-}8)$

$N = 6 \quad F = 60.14 \quad P > F = 0.0038 \quad R^2 = 0.98$

Small catfishes (≤ 114 mm TL)

density = $0.096 - 0.541\ (SUA)$

$N = 22 \quad F = 11.5 \quad P > F = 0.0029 \quad r^2 = 0.37$

density = $-0.096 + 0.443\ (SPSR) - 0.411\ (SUA) - 0.570\ (FSR)$

$N = 22 \quad F = 8.9 \quad P > F = 0.0008 \quad R^2 = 0.60$

Intermediate catfishes ($114 <$ mm TL ≤ 318)

density = $0.024 - 0.504\ (dA/yr)$

$N = 21 \quad F = 7.1 \quad P > F = 0.0153 \quad r^2 = 0.28$

density = $0.040 - 0.238\ (FA) - 0.373\ (dA/yr)$

$N = 21 \quad F = 4.4 \quad P > F = 0.0288 \quad R^2 = 0.33$

Small channel catfish (≤ 114 mm TL)

biomass = $0.014 - 0.523\ (dA/yr)$

$N = 22 \quad F = 9.4 \quad P > F = 0.0061 \quad r^2 = 0.32$

biomass = $0.029 - 0.289\ (SPA) - 0.474\ (dA/yr)$

$N = 22 \quad F = 7.3 \quad P > F = 0.0044 \quad R^2 = 0.44$

density = $0.098 - 0.551\ (SUA)$

$N = 22 \quad F = 12.2 \quad P > F = 0.0023 \quad r^2 = 0.38$

Intermediate channel catfish ($114 <$ mm TL ≤ 318)

density = $0.023 - 0.472\ (dA/yr)$

$N = 21 \quad F = 6.0 \quad P > F = 0.0246 \quad r^2 = 0.24$

Small flathead catfish (≤ 114 mm TL)

density = $-0.096 + 0.689\ (SPSR)$

$N = 8 \quad F = 11.9 \quad P > F = 0.0139 \quad r^2 = 0.66$

APPENDIX C (Continued)

Small flathead catfish (continued)

density = $-1.548 + 0.803\ (\mathrm{SPSR}) - 3.191\ (\mathrm{FSR})$

$N = 8 \quad F = 13.9 \quad P > F = 0.0091 \quad R^2 = 0.84$

Intermediate flathead catfish ($114 <$ mm TL ≤ 318 mm)

biomass = $0.047 + 0.581\ (\mathrm{dA3\text{-}5})$

$N = 16 \quad F = 7.3 \quad P > F = 0.0172 \quad r^2 = 0.34$

biomass = $-0.167 + 0.392\ (\mathrm{SPA}) + 0.942\ (\mathrm{dA3\text{-}5}) + 0.648\ (\mathrm{dA6\text{-}8})$

$N = 16 \quad F = 5.5 \quad P > F = 0.0134 \quad R^2 = 0.58$

Small common carp (≤ 114 mm TL) - NO SIGNIFICANT RELATIONS

Intermediate common carp ($114 <$ mm TL ≤ 318)

density = $0.121 + 0.735\ (\mathrm{SPSR})$

$N = 11 \quad F = 40.9 \quad P > F = 0.0001 \quad r^2 = 0.82$

density = $-0.0001 + 0.731\ (\mathrm{SPSR}) + 0.248\ (\mathrm{SUA})$

$N = 11 \quad F = 43.4 \quad P > F = 0.0001 \quad R^2 = 0.92$

Small buffalofishes (≤ 114 mm TL)

biomass = $0.151 - 0.632\ (\mathrm{FSR}) + 0.894\ (\mathrm{dA8\text{-}10})$

$N = 7 \quad F = 11.5 \quad P > F = 0.0220 \quad r^2 = 0.85$

density = $-0.012 - 0.808\ (\mathrm{SPA})$

$N = 7 \quad F = 9.0 \quad P > F = 0.0304 \quad r^2 = 0.64$

density = $-0.140 - 1.115\ (\mathrm{SPA}) - 0.639\ (\mathrm{FSR})$

$N = 7 \quad F = 12.5 \quad P > F = 0.0189 \quad R^2 = 0.86$

Small spotted suckers (≤ 89 mm TL) - NO SIGNIFICANT RELATIONS

Intermediate spotted suckers ($89 <$ mm TL ≤ 318)

biomass = $0.505 - 0.969\ (\mathrm{dA6\text{-}8})$

$N = 10 \quad F = 16.9 \quad P > F = 0.0034 \quad r^2 = 0.68$

APPENDIX C (Concluded)

Intermediate spotted suckers (continued)

biomass = 0.475 - 0.864 (6-8) + 0.286 (8-10)

N = 10 F = 11.2 $P > F = 0.0066$ $R^2 = 0.76$

Small freshwater drum ($\leq$ 114 mm TL)

biomass = 0.051 + 0.546 (SPSR)

N = 19 F = 11.1 $P > F = 0.0039$ $r^2 = 0.40$

biomass = 0.012 + 0.252 (SPSR) - 0.721 (SPA) + 0.618 (SUA)

N = 19 F = 7.9 $P > F = 0.0022$ $R^2 = 0.61$

Small threadfin shad ($\leq$ 89 mm TL)

Sample size was insufficient

Small gizzard shad ($\leq$ 114 mm TL)

biomass = 0.079 - 0.466 (FA) + 0.454 (dA8-10)

N = 23 F = 6.0 $P > F = 0.0091$ $R^2 = 0.38$

density = 0.041 + 0.232 (SUA) - 0.513 (FA) + 0.513 (dA8-10)

N = 23 F = 6.0 $P > F = 0.0049$ $R^2 = 0.48$

Intermediate gizzard shad (114 $<$ mm TL $\leq$ 241)

density = 0.076 - 0.381 (SUA)

N = 23 F = 4.4 $P > F = 0.0484$ $r^2 = 0.17$

Minnows (all species and sizes)

biomass = 0.136 - 0.681 (SUA)

N = 23 F = 26.1 $P > F = 0.0001$ $r^2 = 0.55$

biomass = 0.260 - 0.880 (SUA) - 0.389 (dA6-8)

N = 23 F = 17.0 $P > F = 0.0001$ $R^2 = 0.63$

APPENDIX D: MEANS AND STANDARD DEVIATIONS (SD) OF FISH VARIABLES IN THE THREE RESERVOIR SAMPLES

Means and Standard Deviations (SD) of Fish Variables in the Three Reservoir Samples

Common Names of Fish Variables	Scientific Names or Groups	Length Range, mm	Hydropower Storage Sample Biomass Mean	± SD	Hydropower Storage Sample Density Mean	± SD	Hydropower Mainstream Sample Biomass Mean	± SD	Hydropower Mainstream Sample Density Mean	± SD	Flood Control Sample Biomass Mean	± SD	Flood Control Sample Density Mean	± SD
Reservoir fishes	All species	All sizes	226	113	6,709	2,795	386	243	9,262	6,733	306	342	11,364	23,127
Small reservoir fishes	All species	0-114	52.5	27.3	5,555	2,616	61.2	67.1	7,490	5,910	72.4	160	10,45[illegible]	23,000
Intermediate reservoir fishes	All species	115-318	112	96.5	1,118	1,348	222	144	1,737	1,334	117	107	846	[illegible],077
Sport fishes	Centrarchidae, *Esox* spp., *Ictalurus* spp., *Morone* spp., and *Stizostedion* spp.	All sizes	86.2	47.1	3,332	851	99.2	107	3,534	3,547	68.1	38.9	2,382	[illegible],849
Small sport fishes		0-114	35.6	13.0	2,993	833	27.2	32.2	2,913	2,870	15.1	11.8	2,179	1,822
Intermediate sport fishes		115-318	38.2	30.4	390	390	60.9	66.5	614	826	31.1	23.9	190	175
Small black basses	*Micropterus* spp.	0-114	1.7	2.7	238	355	0.8	0.71	87.1	68.2	1.3	1.2	110	120
Intermediate black basses		115-318	5.5	10.4	40.5	124	4.5	3.2	21.5	15.7	6.0	4.4	22.2	18.3
Small largemouth bass	*Micropterus salmoides*	0-114	1.3	2.1	185	277	0.8	0.73	82.4	72.4	1.1	0.9	92.4	87.9
Intermediate largemouth bass		115-318	4.6	9.8	35.1	122	4.6	3.2	21.6	15.9	4.7	3.2	17.4	14.9
Small spotted bass	*Micropterus punctulatus*	0-114	0.9	0.7	118.8	93.4	0.1	0.11	11.8	16.4	0.3	0.4	28.8	46.9
Intermediate spotted bass		115-318	1.9	1.5	10.9	6.3	0.2	0.31	1.2	1.1	2.9	1.5	7.1	6.4
Small smallmouth bass	*Micropterus dolomieui*	0-114	0.1	0.08	11.6	7.6	0.1	0.78	8.5	8.7	0.1	0.10	6.5	5.5
Intermediate smallmouth bass		115-318	0.5	0.33	2.6	1.7	0.3	0.44	1.7	2.9	0.3	0.17	1.6	0.9
Small crappies	*Pomoxis* spp.	0-89	0.6	0.79	196	280	0.1	0.15	40.1	61.8	4.2	9.2	848	1,696
Intermediate crappies		90-140	1.6	2.7	36.4	60.5	0.5	0.70	12.0	16.1	0.4	0.50	11.3	16.6
Small white crappie	*Pomoxis annularis*	0-89	0.3	0.39	102	181	0.1	0.12	21.8	28.9	4.5	9.8	933	1,806
Intermediate white crappie		90-140	1.0	2.0	21.1	44.4	0.2	0.12	4.8	3.2	0.3	0.5	6.2	8.4
Small black crappie	*Pomoxis nigromaculatus*	0-89	0.5	0.78	140	246	0.1	0.15	28.1	67.1	0.2	0.29	14.2	9.4
Intermediate black crappie		90-140	1.0	2.1	22.7	47.9	0.5	0.84	11.6	19.6	0.1	0.12	2.1	2.6
Small lepomid sunfishes	*Lepomis* spp.	0-89	16.6	5.6	1,919	752	9.6	9.2	2,199	2,321	4.7	4.2	951	1,031
Intermediate lepomid sunfishes		90-140	24.6	17.5	570	388	34.6	50.1	685	1,023	7.8	9.4	154	180
Small bluegills	*Lepomis macrochirus*	0-89	10.0	8.3	1,141	897	7.2	7.9	1,762	2,143	3.7	3.5	823	1,037
Intermediate bluegills		90-140	14.9	17.2	362	411	22.7	33.5	478	745	5.6	6.4	111	122
Small green sunfish	*Lepomis cyanellus*	0-89	1.9	2.0	296	371	0.9	0.48	112	78.6	0.5	0.83	67.4	87.1
Large green sunfish		90-	2.9	4.7	78.9	83.2	1.7	0.74	33.1	16.4	0.9	1.8	23.5	53.5
Small warmouth	*Lepomis gulosus*	0-89	0.6	0.89	96.2	184	0.4	0.29	46.0	27.7	0.3	0.38	60.4	75.0
Intermediate warmouth		90-140	0.5	0.52	12.4	13.8	1.6	1.8	29.2	35.2	0.5	0.71	8.3	12.7
Small redear sunfish	*Lepomis microlophus*	0-89	0.1	0.15	8.3	7.0	0.02	0.02	2.5	4.2				
Intermediate redear sunfish		90-140	0.3	0.20	8.0	7.4	0.8	1.2	10.5	16.1	0.1	0.09	1.0	0.91
Small temperate basses	*Morone* spp.	0-114	0.2	0.25	12.6	18.6	0.1	0.12	4.3	5.0	0.2	0.29	9.5	12.0
Intermediate temperate basses		115-318	3.6	6.9	23.6	44.6	0.9	1.34	4.5	4.4	3.4	6.2	15.8	30.0
Small white bass	*Morone chrysops*	0-114	0.2	0.28	7.3	11.3	0.1	0.12	3.9	5.2	0.2	0.30	9.4	11.9
Intermediate white bass		115-318	4.8	7.6	31.1	49.6	0.8	1.3	3.2	3.4	3.6	6.4	16.6	30.5
Small yellow perch	*Perca flavescens*	0-89	1.0	0.9	162	165	1.4	1.6	217	172				
Small walleye	*Stizostedion vitreum vitreum*	0-140	0.01	0.01	0.3	0.29					0.1	0.13	6.1	6.7
Intermediate walleye		140-318	0.2	0.22	1.5	2.2					0.6	0.36	7.5	6.8
Intermediate sauger	*Stizostedion canadense*	140-318					1.0	2.0	5.6	13.8				
Small catfishes	*Ictalurus* spp. and *Pylodictis* sp.	0-114	0.2	0.15	23.6	17.0	0.2	0.4	23.3	43.8	0.3	0.40	90.7	219
Intermediate catfishes		115-318	3.8	4.5	18.5	22.2	2.3	3.1	7.5	9.2	3.9	2.7	20.3	15.2
Small channel catfish	*Ictalurus punctatus*	0-114	0.1	0.09	13.2	12.2	0.2	0.29	25.6	54.8	0.3	0.40	89.5	219
Intermediate channel catfish		115-318	2.4	3.2	12.1	16.5	1.4	2.9	5.1	9.2	3.3	2.5	18.5	14.0
Small flathead catfish	*Pylodictis olivaris*	0-114	0.01	0.02	4.7	3.9	0.02	0.02	3.0	4.1	0.04	0.06	3.2	5.1
Intermediate flathead catfish		115-318	0.2	0.14	1.0	0.8	0.3	0.30	1.5	1.3	0.7	0.53	2.4	2.2
Small common carp	*Cyprinus carpio*	0-114	0.1	0.10	1.3	1.3					1.3	1.3	78.8	95.2
Intermediate common carp		115-318	1.8	4.0	6.0	13.7	15.8	20.7	23.7	34.0	21.6	33.7	49.1	61.8
Intermediate redhorses	*Moxostoma* spp.	89-318	6.1	5.0	17.0	14.9	0.3	0.26	1.0	0.6	0.8	0.80	4.2	4.7
Intermediate golden redhorse	*Moxostoma erythrurum*	89-318	5.0	4.0	12.4	11.6	0.3	0.28	0.9	0.73				
Small buffalofishes	*Ictiobus* spp.	0-89					0.5	0.63	3.3	6.6	1.3	2.1	3.2	3.4
Intermediate spotted suckers	*Minytrema melanops*	0-89	2.5	3.3	5.2	6.9	0.6	0.60	1.4	1.1	2.0	2.9	6.4	9.2
Small freshwater drum	*Aplodinotus grunniens*	0-114					0.9	1.65	116	236	1.4	1.6	140	128
Small threadfin shad	*Dorosoma petenense*	0-89	10.0	15.2	2,265	2,409	8.6	9.2	2,239	2,216	4.8	6.6	1,273	1,745
Large threadfin shad		89-140	2.8	4.7	129	225	11.2	13.2	528	1,725	2.4	3.9	138	228
Small gizzard shad	*Dorosoma cepedianum*	0-114	7.7	12.0	731	1,132	20.8	44.6	2,068	4,009	51.2	161	6,784	23,278
Intermediate gizzard shad		115-241	52.6	77.2	620	1,046	12[illegible]	150	1,018	1,287	45.5	90.5	535	946
Golden shiner	*Notemigonus crysoleucas*	All sizes	0.9	0.87	17.0	11.6	[illegible]	1.5	11.3	15.3	3.2	4.4	9.2	11.7
Minnows	*Notropis* spp., *Notemigonus* spp., *Pimephales* spp., *Fundulus* spp., Atherinidae	All sizes	0.8	0.72	92.7	[illegible]	1.4	1.5	426.6	501.3	2.6	3.8	888	1,671